Tanta University

Faculty of Engineering

ELECTRICAL POWER ENGINEERING (1)

DC DISTRIBUTION

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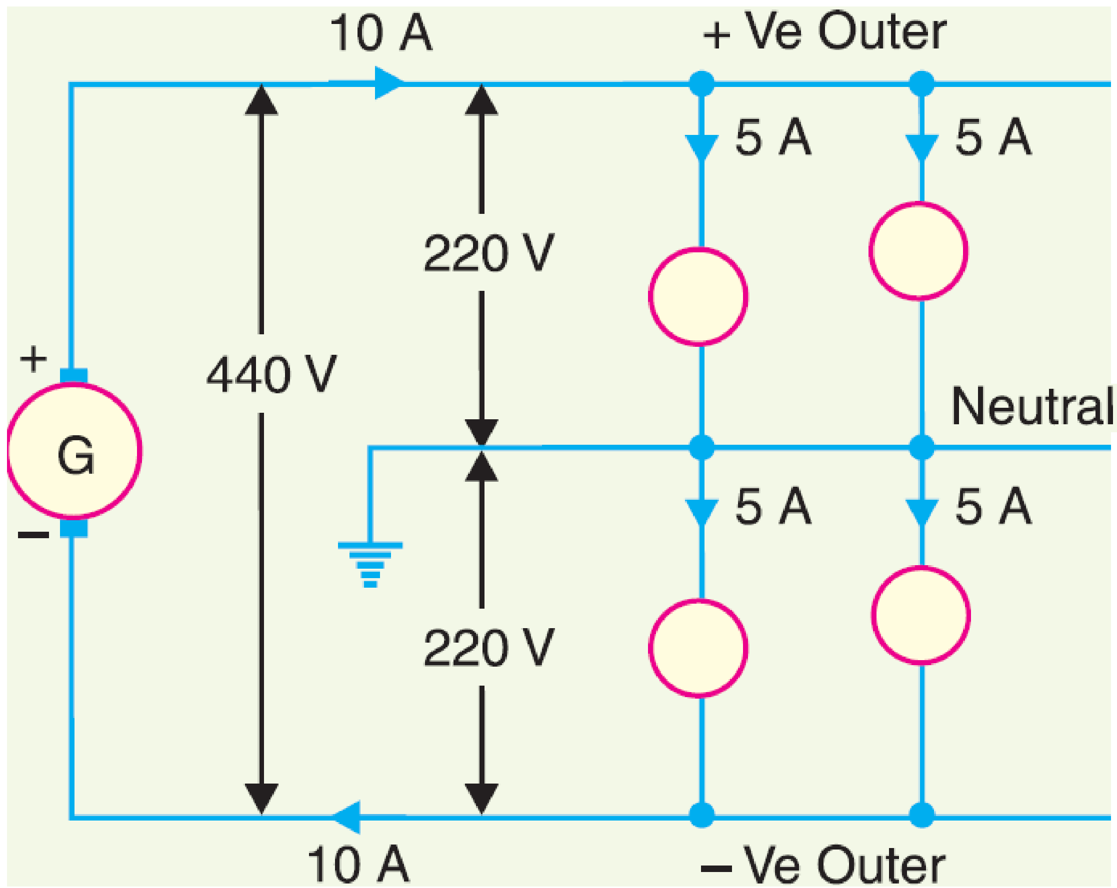
Three-Wire D.C. System

Three wire d.c. system can provide two voltages: V volts between any outer and neutral and 2V volts between the outers

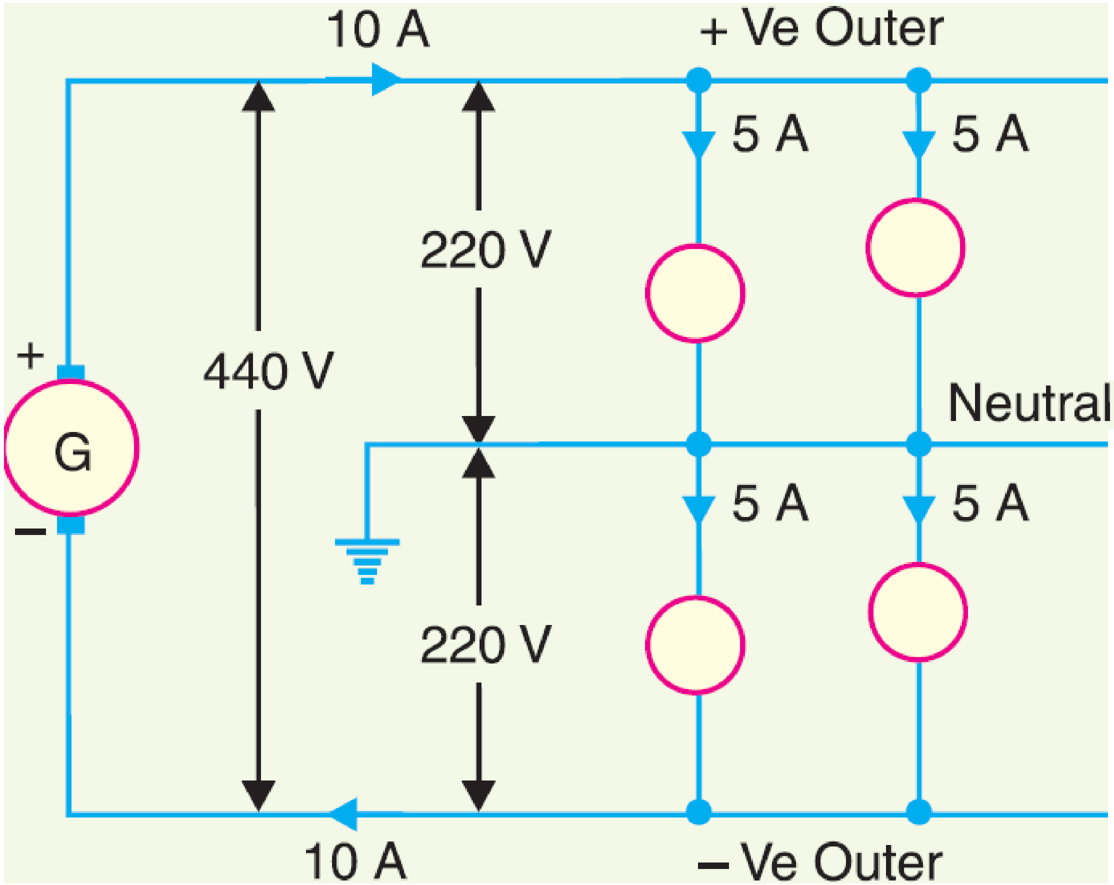
Motors needing high voltage are fixed between the outers where lighting and heating loads needing less voltage are connected between any one outer and the neutral



Three-Wire D.C. System

(i) If the loads applied on both sides of the neutral are equal, the current in the neutral wire will be zero

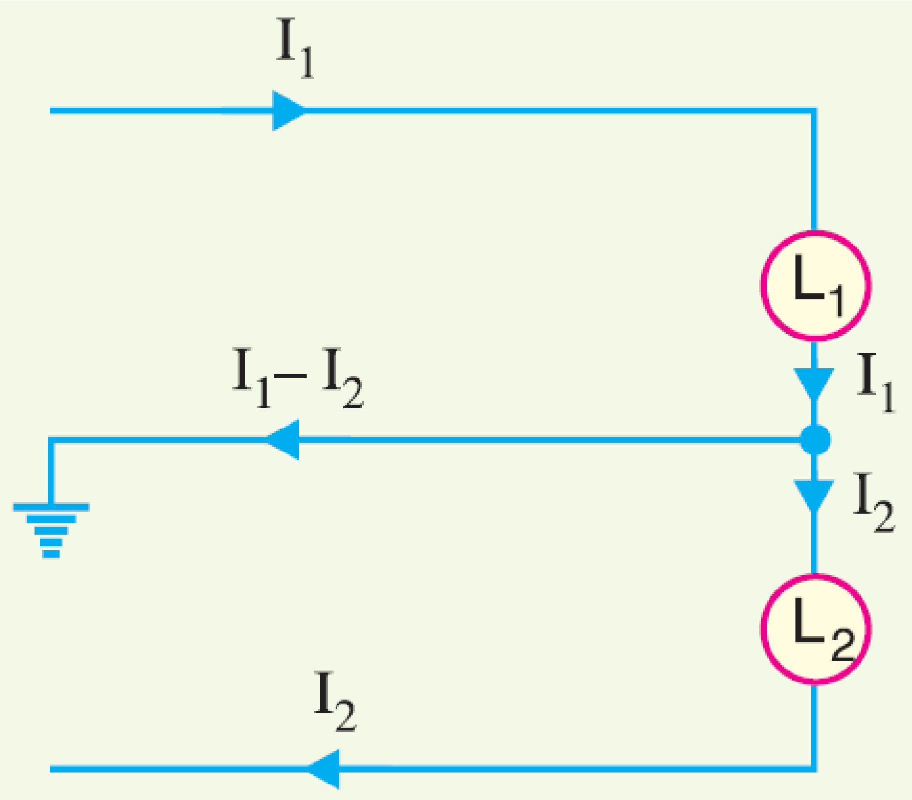
The potential of the neutral will be exactly half-way between the potential difference of the outers



Three-Wire D.C. System

(ii) If the load on the positive outer (I_1) is greater than on the negative outer (I_2), the difference ($I_1 - I_2$) will flow in the neutral wire from load end to supply end

The potential of neutral wire will no longer be midway between the potentials of the outers



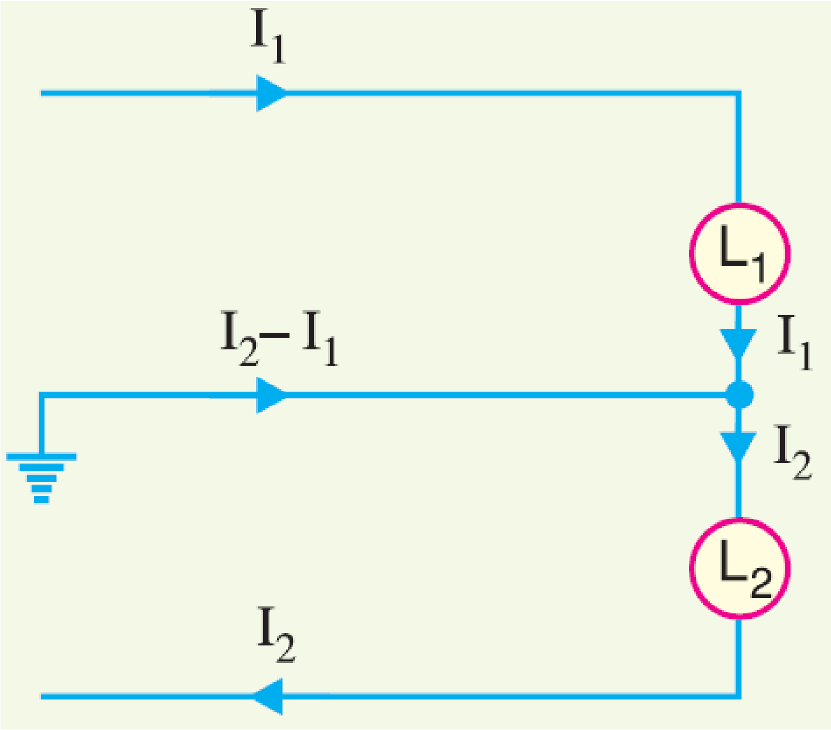
Three-Wire D.C. System

(iii) If the load on the negative outer (I_2) is greater than on the positive outer (I_1), the difference ($I_2 - I_1$) will flow in the neutral from supply end to load end

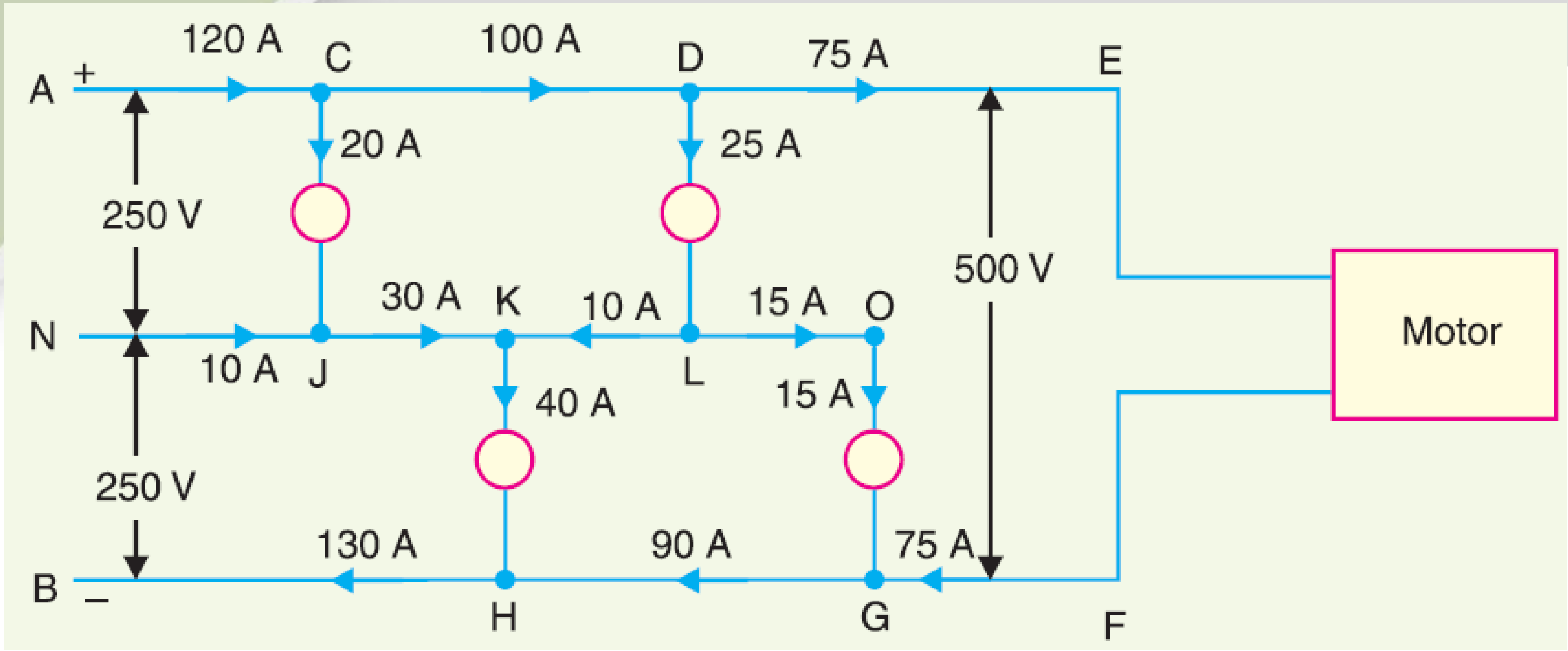
Again, the neutral potential will not remain half-way between that of the outers

It is desirable that voltage between any outer and the neutral should have the same value

This is achieved by distributing the loads equally on both sides of the neutral



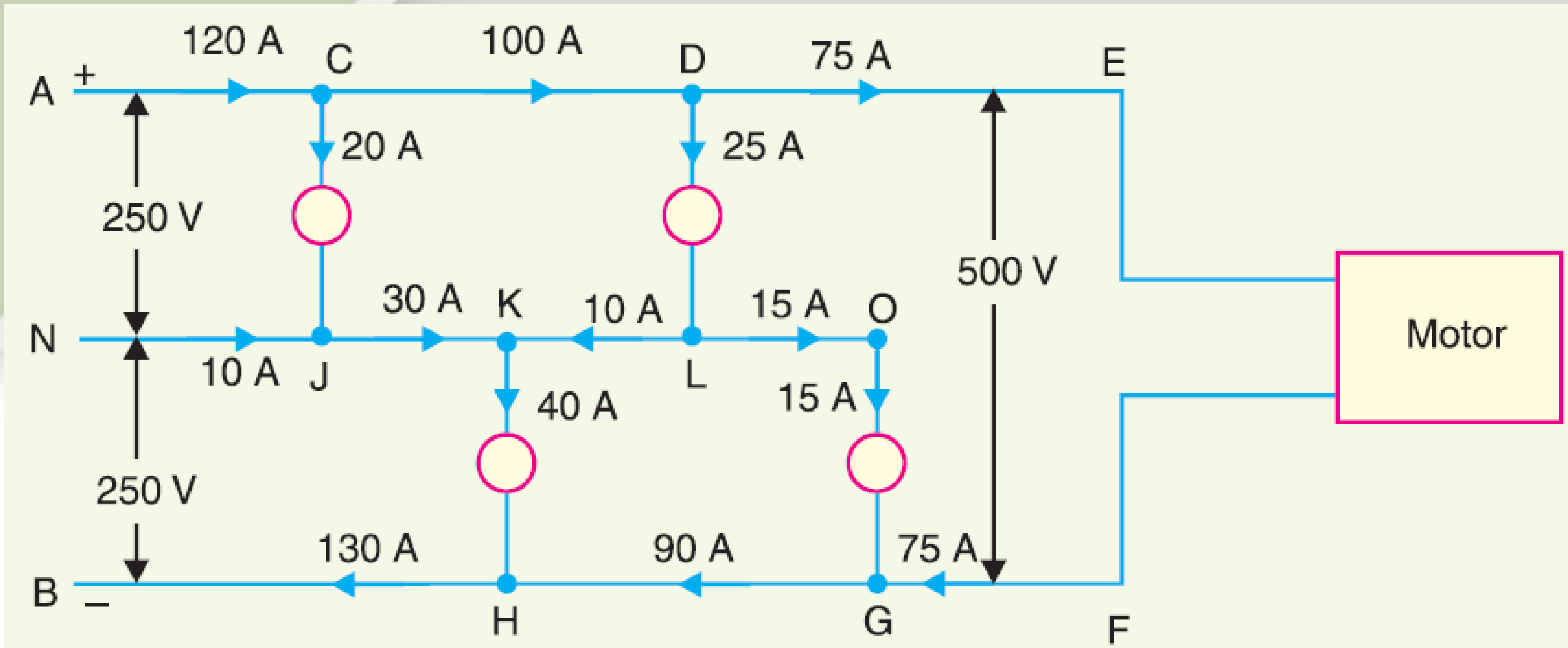
Current Distribution in 3-Wire D.C. System



It is clear that a current of 120 A enters the positive outer, while 130 A comes out of the negative outer

130 – 120 = 10 A must flow in the neutral at point N

Load-point voltages

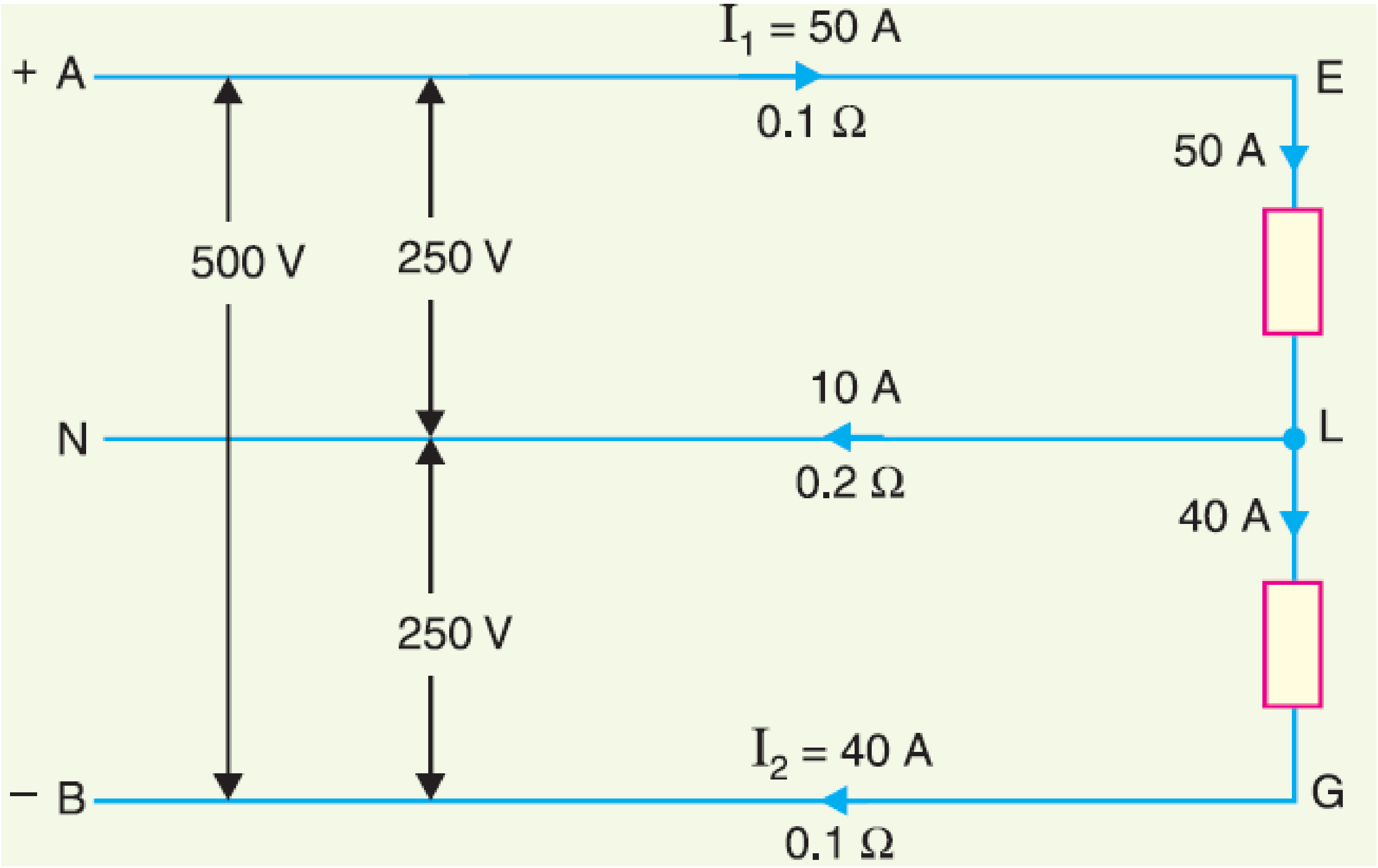


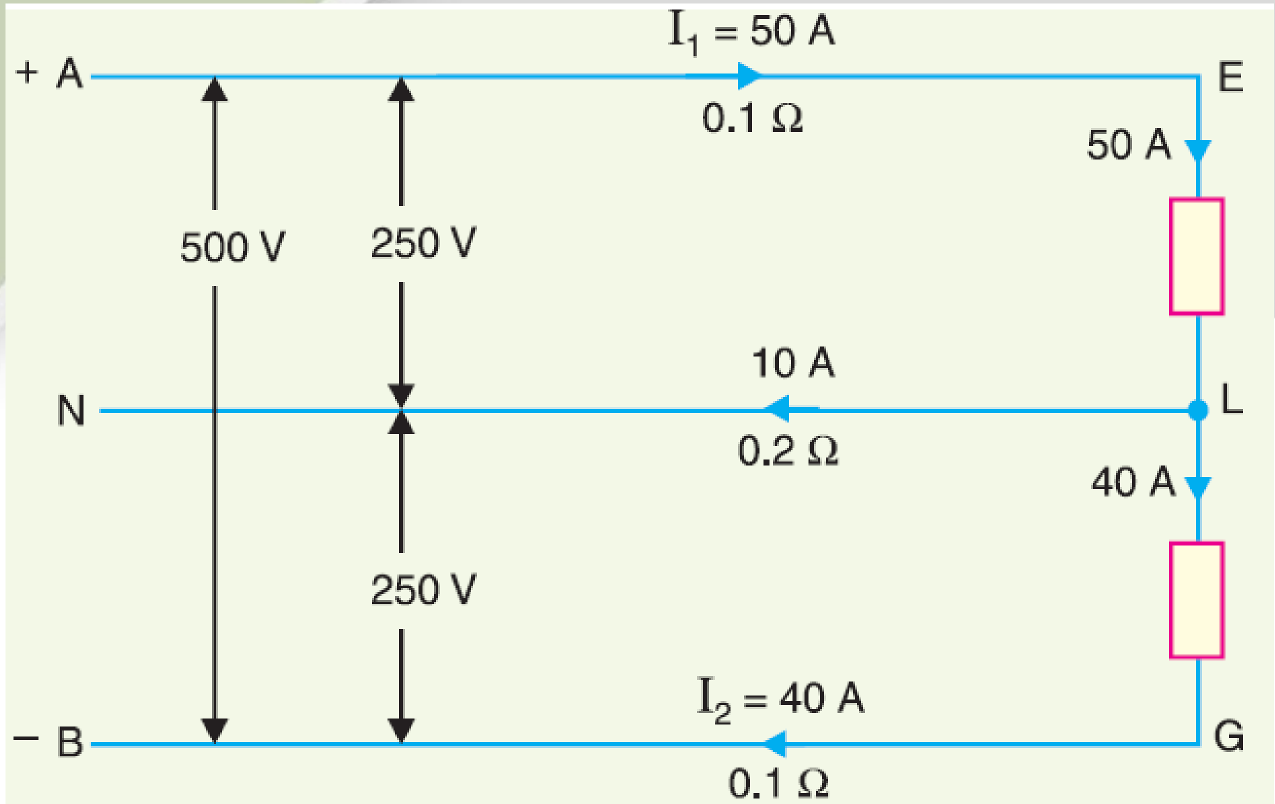
The voltage across load CJ is obtained by applying Kirchhoff's voltage law to the loop ACJNA

Voltage across CJ = 250 – drop in AC + drop in NJ

Example: A load supplied on 3-wire d.c. system takes a current of 50 A on the +ve side and 40 A on the -ve side. The resistance of each outer wire is 0.1 Ω and the cross-section of middle wire is one-half of that of outer. If the system is supplied at 500/250 V, find the voltage at the load end between each outer and middle wire.

Example: A load supplied on 3-wire d.c. system takes a current of 50 A on the +ve side and 40 A on the -ve side. The resistance of each outer wire is 0.1 Ω and the cross-section of middle wire is one-half of that of outer. If the system is supplied at 500/250 V, find the voltage at the load end between each outer and middle wire.



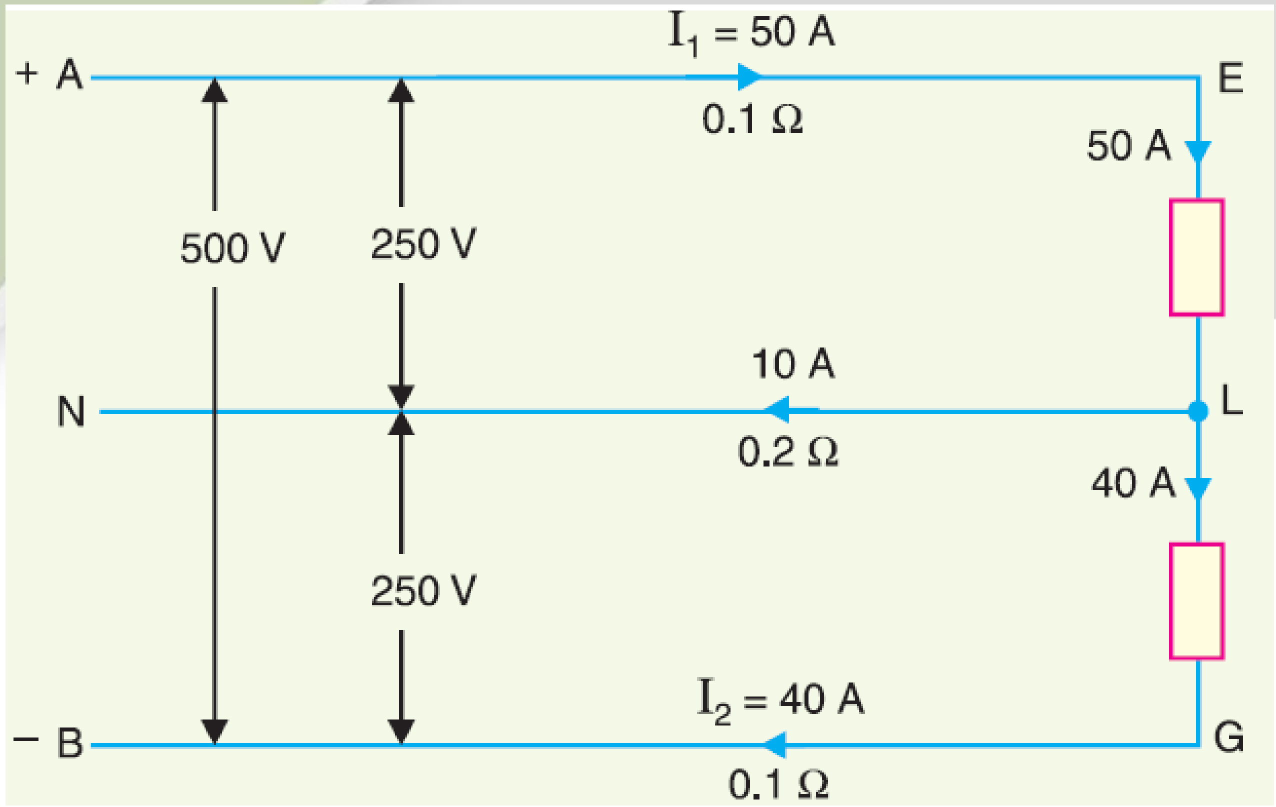


Current in the neutral wire is 50 − 40 = 10A

As the X-sectional area of neutral is half that of outer, therefore, its resistance = 2 × 0.1 = 0.2 Ω

Voltage at the load end on the +ve side,

$V_{EL}=250-I_1 R_{AE} - (I_1-I_2) R_{NL}=250-50\times0.1- (10)\times0.2=243V$

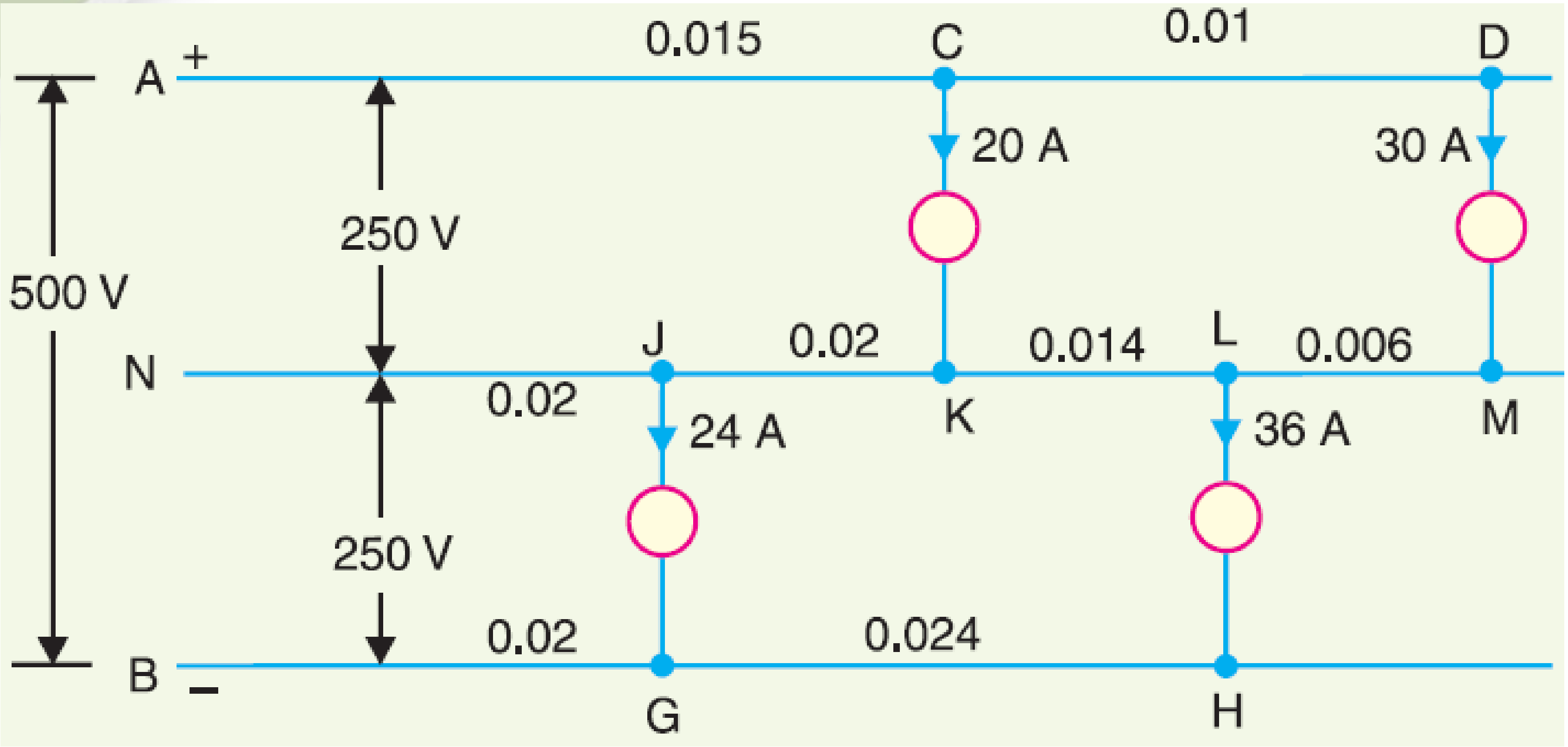


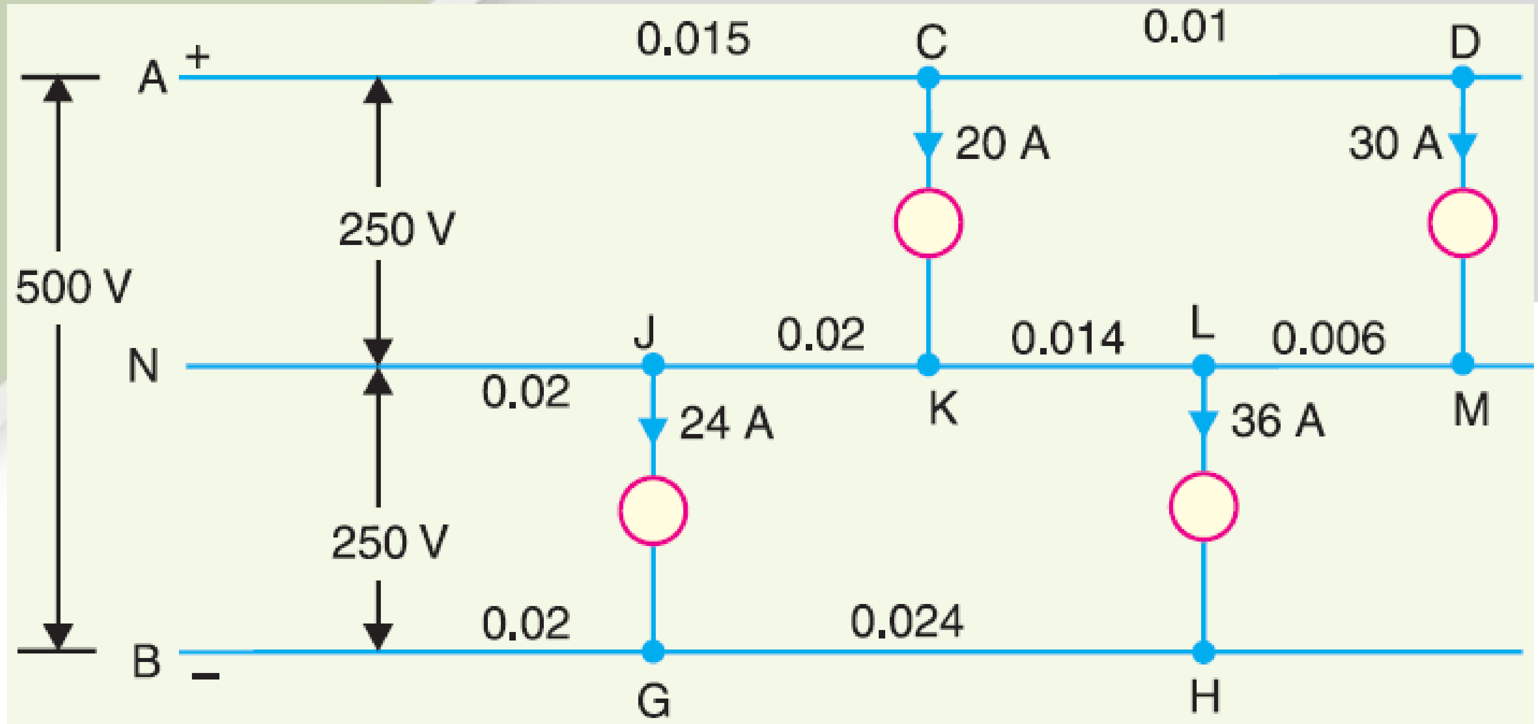
Voltage at the load end on the −ve side,

$$V_{LG} = 250 + (I_1 - I_2)\, R_{NL} - I_2\, R_{BG}$$

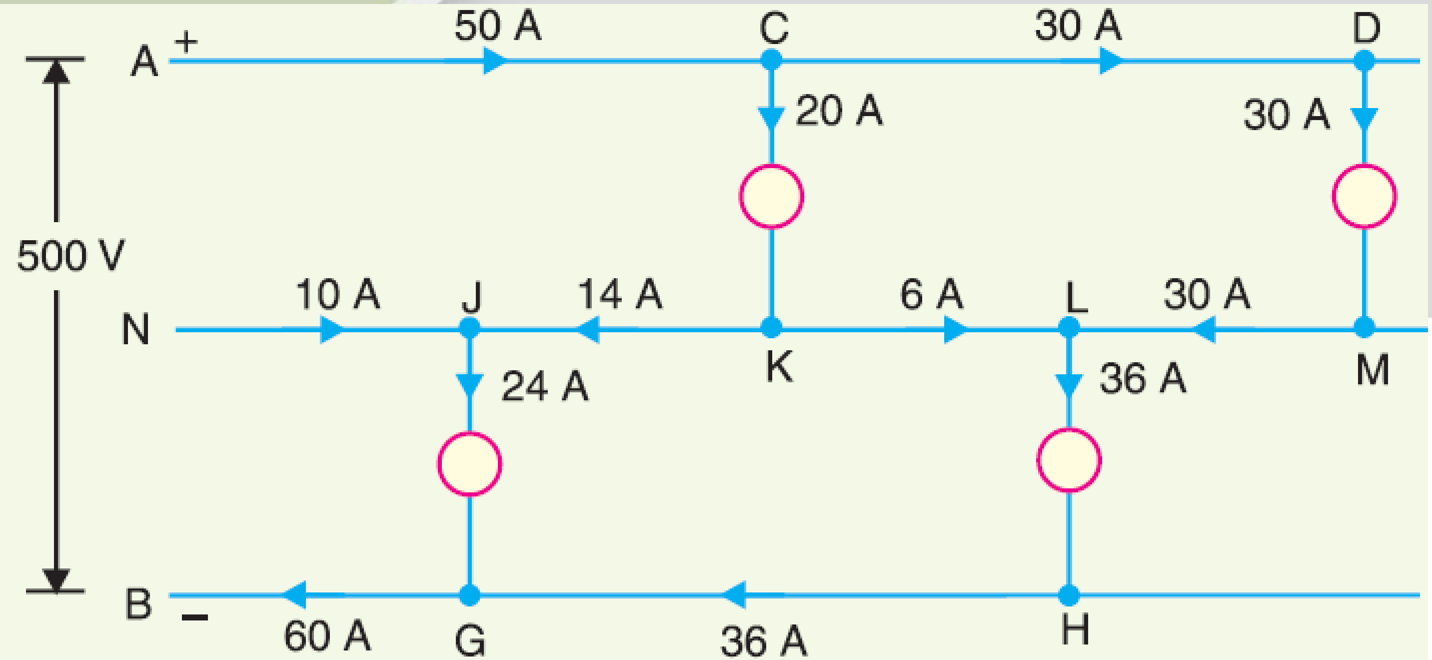
$$= 250 + 10 \times 0.2 - 40 \times 0.1 = 248V$$

Example: A 3-wire, 500/250 V distributor is loaded as shown. The resistance of each section is given in ohm. Find the voltage across each load point.





Section	*Resistance* (Ω)	*Current* (*A*)	*Drop* (*V*)
AC	0·015	50	0·75
CD	0·01	30	0·3
ML	0·006	30	0·18
KL	0·014	6	0·084
KJ	0·02	14	0·28
NJ	0·02	10	0·2
HG	0·024	36	0·864
GB	0·02	60	1·2



Voltage across load *CK = 250 - drop in AC - drop in KJ + drop in NJ* = 250 − 0.75 − 0.28 + 0.2 = **249.17 V**

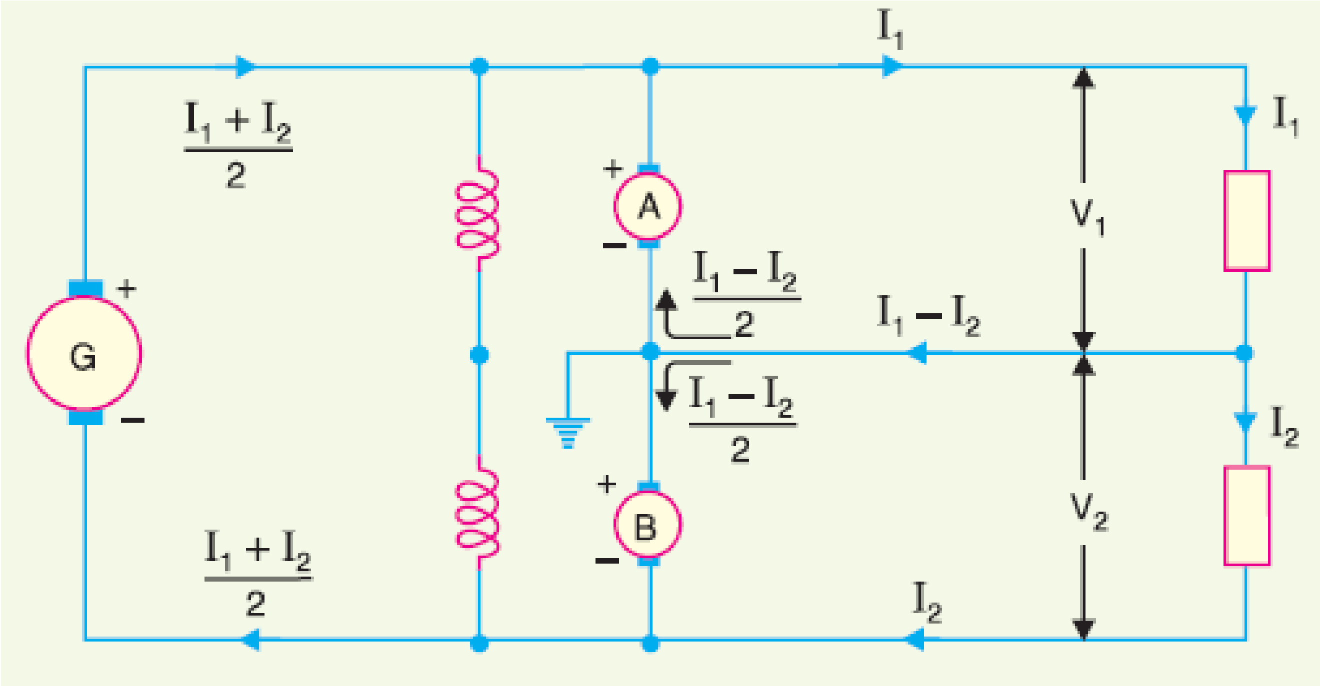
Voltage across load *DM = 249.17 - drop in CD - drop in ML+ drop in KL* = 249.17 - 0.3 - 0.18 + 0.084 = **248.774V**

Voltage across load *JG = 250 - drop in NJ - drop in GB* = 250 - 0·2 - 1·2 = **248·6 V**

Voltage across load *LH = 248·6 + drop in KJ - drop in KL - drop in HG* = 248.6 + 0.28 - 0.084 - 0·864 = **247.932 V**

Balancers in 3-Wire D.C. System

- In order to maintain voltages on the two sides of the neutral equal to each other, a *balancer set* is used.
- The balancer is consists of two identical shunt wound machines A and B coupled mechanically and having their armature and field circuits connected in series across the outers.

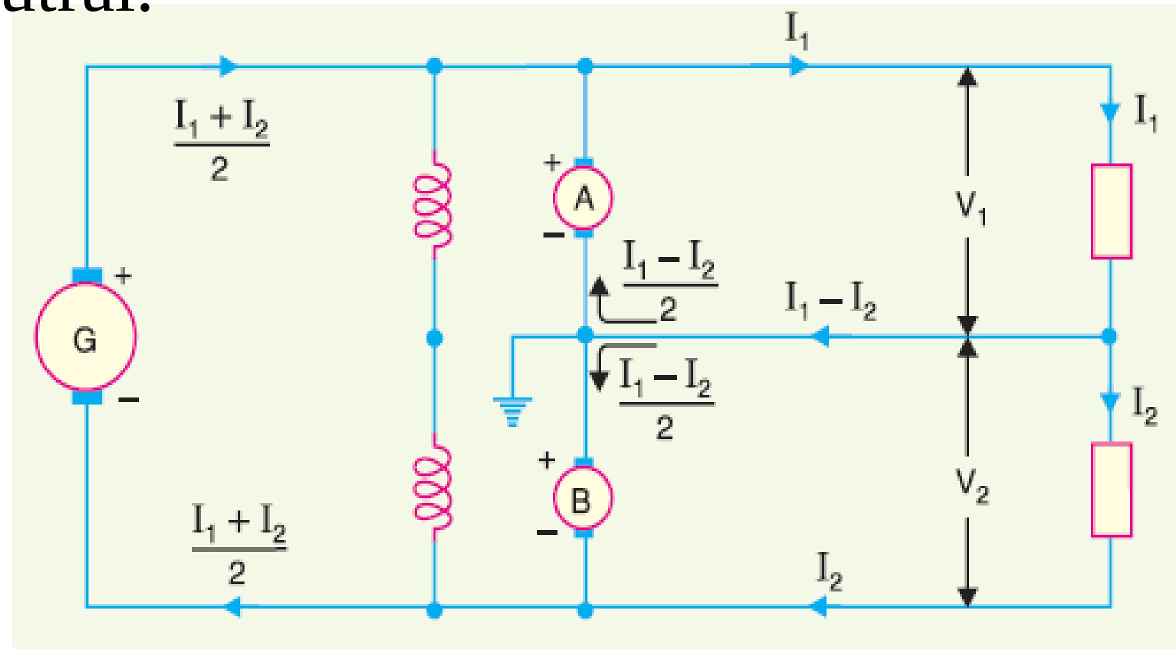


Balancers in 3-Wire D.C. System

- The neutral wire is connected to the junction of the armatures.
- The circuit arrangement has two obvious advantages.

1. Only one generator (G) is required which results in a great saving in cost.
2. The balancer set tends to equalize the voltages on the two sides of the neutral.

$$\boldsymbol{E = V + I_a R_a}$$
$$\boldsymbol{E > V \quad (G)}$$
$$\boldsymbol{E = V \quad (no\ load)}$$
$$\boldsymbol{E < V \quad (M)}$$



Balancers in 3-Wire D.C. System

Example 13.33. *A d.c. 3-wire system with 500 V between outers has lighting loads of 150 kW on the positive side and 100 kW on the negative side. The loss in each balancer machine is 3 kW. Calculate :*

(i) total load on the main generator

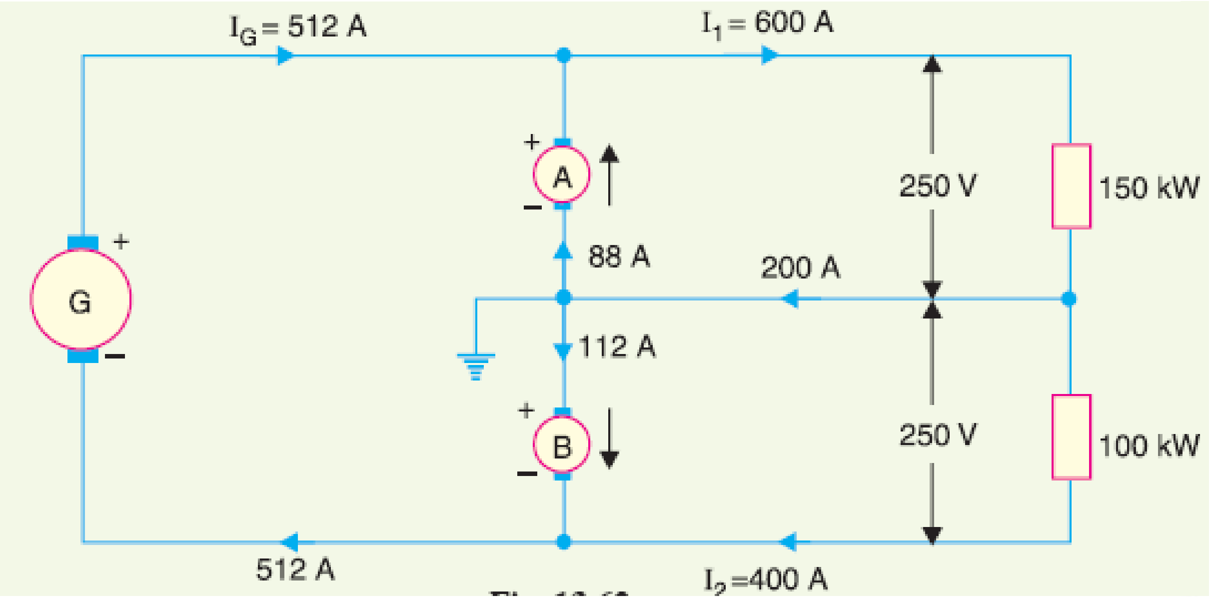
(ii) kW loading of each balancer machine

Solution. The connections are shown in Fig. 13.62. As the positive side is more heavily loaded, therefore, machine *A* acts as a generator and machine *B* as a motor.

(i) Total load on the main generator

= load on +ve side + load on –ve side + losses

= 150 + 100 + 2 × 3 = **256 kW**



Balancers in 3-Wire D.C. System

(*ii*) Current supplied by the main generator,

$$I_G = 256 \times 10^3/500 = 512 \text{ A}$$

Load current on +ve side, $I_1 = 150 \times 10^3/250 = 600$ A

Load current on –ve side, $I_2 = 100 \times 10^3/250 = 400$ A

Current in neutral wire $= I_1 - I_2 = 600 - 400 = 200$ A

Current through machine *A* $= I_1 - I_G = 600 - 512 = 88$ A

Current through machine *B* $= I_G - I_2 = 512 - 400 = 112$ A

$\therefore$ Load on machine *A* $= 88 \times 250/1000 =$ **22 kW**

Load on machine *B* $= 112 \times 250/1000 =$ **28 kW**

Elements of Power System

It has already been pointed out that for transmission of electric power, 3-phase, 3-wire a.c. system is universally adopted. However, other systems can also be used for transmission under special circumstances. ***The different possible systems of transmission are:***

1. D.C. system

(***i***) D.C. two-wire.
(***ii***) D.C. two-wire with mid-point earthed.
(***iii***) D.C. three-wire.

2. Single-phase A.C. system

(***i***) Single-phase two-wire.
(***ii***) Single-phase two-wire with mid-point earthed.
(***iii***) Single-phase three-wire.

3. Two-phase A.C. system

(***i***) Two-phase four-wire.
(***ii***) Two-phase three wire.

4. Three-phase A.C. system

(***i***) Three-phase three-wire.
(***ii***) Three-phase four-wire.

AC Distribution

A.C. distribution differ from D.C. distribution in:

(i) The voltage drops are due to the combined effects of resistance, inductance and capacitance

(ii) The additions and subtractions of currents or voltages are done vectorially

(iii) The power factor (p.f.) has to be taken into account. Loads tapped off from the distributor are generally at different power factors.

Method of solving A.C. distribution problems

There are two ways of referring power factor:

(a) It may be referred to supply or receiving end voltage which is regarded as the reference vector

(b) It may be referred to the voltage at the load point itself

AC Distribution

- If we take a general case:

$$v = V_m \sin(\varpi t + \theta_v)$$

$$i = I_m \sin(\varpi t + \theta_i)$$

- The average power, or real power as it is sometimes called, is the power delivered and dissipated by the load. It corresponds to the power calculations performed for dc networks.

- Defining θ as equal to $/\theta_v\text{-}\theta_i/$, where | | indicates that only the magnitude is important and the sign is not important, we have:

$$P = \frac{V_m I_m}{2} \cos\theta$$

AC Distribution

➢In the equation $P=(V_m I_m/2)\cos\theta$ the factor that has significant control on the delivered power level is the $\cos\theta$. No matter how large the voltage or current, if $\cos\theta=0$, the power is zero; if $\cos\theta=1$,the power delivered is a maximum. Since it has such control, the expression was given the name power factor and is defined by:

$$\boxed{\text{Power factor}=\text{PF}=\cos\theta}$$

➢If the current lags the voltage, it is called a lagging power factor (inductive load) and if it leads the voltage, it is called a leading power factor (capacitive load).

AC Distribution

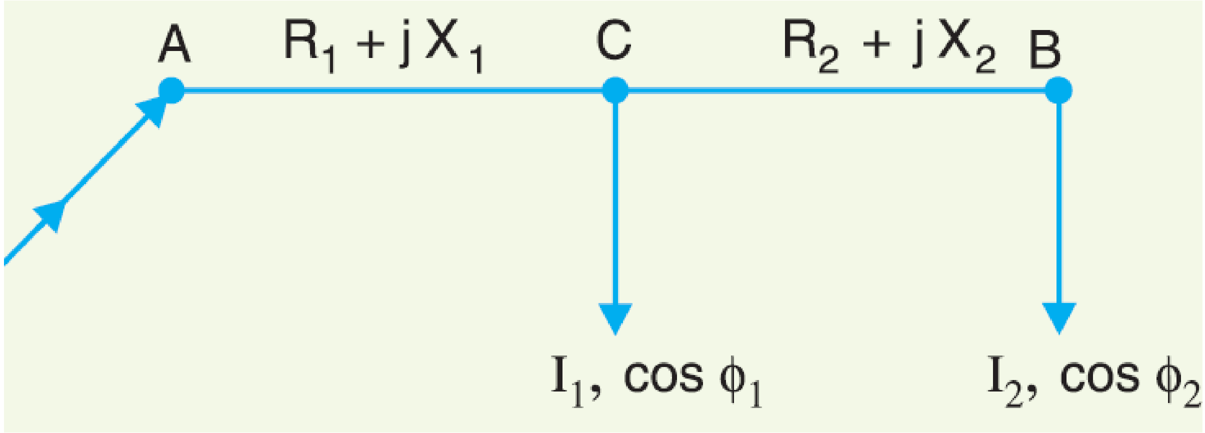
The power factors of load currents may be given:

(i) Power factors referred to receiving or sending end voltage, or

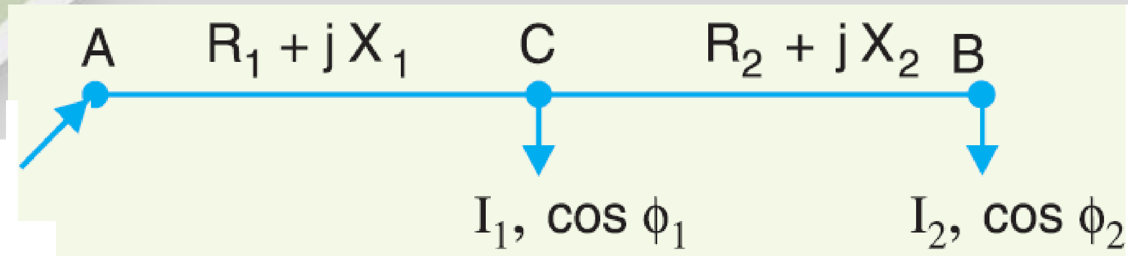
(ii) Power factors referred to load voltage itself

(i) Power factors referred to receiving end **voltage**

Taking receiving end voltage V_B as reference vector and lag. power factors at C and B are cos φ_1 and cos φ_2 w.r.t. V_B



AC Distribution



$$\overrightarrow{Z_{AC}} = R_1 + j\,X_1 \qquad \overrightarrow{Z_{CB}} = R_2 + j\,X_2$$

$$\overrightarrow{I_1} = I_1\,(\cos\phi_1 - j\sin\phi_1) \qquad \overrightarrow{I_2} = I_2\,(\cos\phi_2 - j\sin\phi_2) \quad \Delta$$

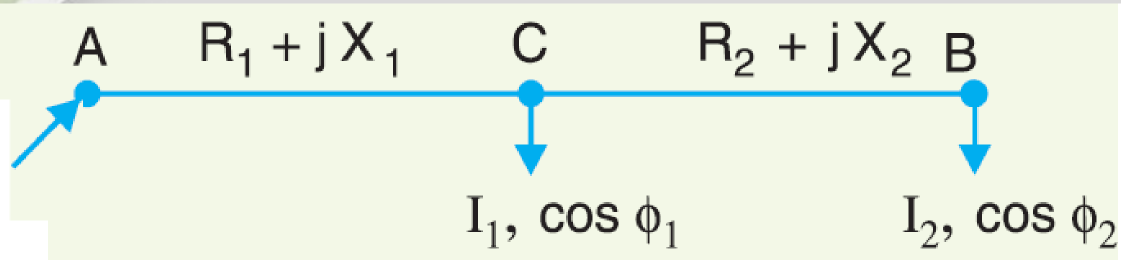
$$\overrightarrow{I_{CB}} = \overrightarrow{I_2} = I_2\,(\cos\phi_2 - j\sin\phi_2)$$

$$\overrightarrow{I_{AC}} = \overrightarrow{I_1} + \overrightarrow{I_2} = I_1\,(\cos\phi_1 - j\sin\phi_1) + I_2\,(\cos\phi_2 - j\sin\phi_2)$$

$$\Delta\overrightarrow{V_{CB}} = \overrightarrow{I_{CB}}\,\overrightarrow{Z_{CB}} = I_2\,(\cos\phi_2 - j\sin\phi_2)\,(R_2 + j\,X_2)$$

$$\Delta\overrightarrow{V_{AC}} = \overrightarrow{I_{AC}}\,\overrightarrow{Z_{AC}} = \left(\overrightarrow{I_1} + \overrightarrow{I_2}\right) Z_{AC}$$

AC Distribution



$$\Delta \overrightarrow{V_{CB}} = \overrightarrow{I_{CB}}\,\overrightarrow{Z_{CB}} = I_2(\cos\phi_2 - j\sin\phi_2)(R_2 + jX_2)$$

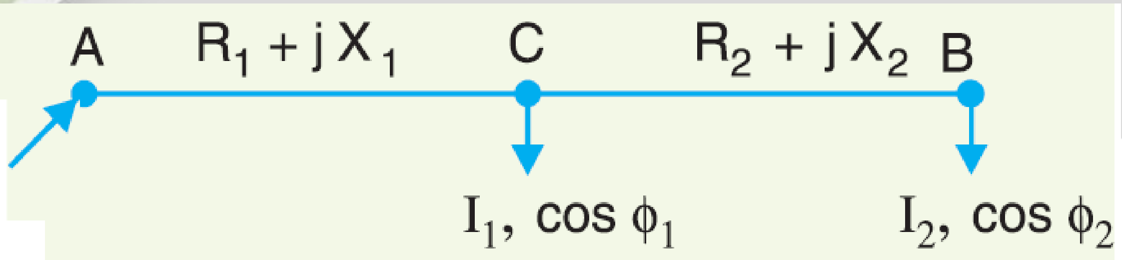
$$\Delta \overrightarrow{V_{AC}} = \overrightarrow{I_{AC}}\,\overrightarrow{Z_{AC}} = \left(\overrightarrow{I_1} + \overrightarrow{I_2}\right) Z_{AC}$$

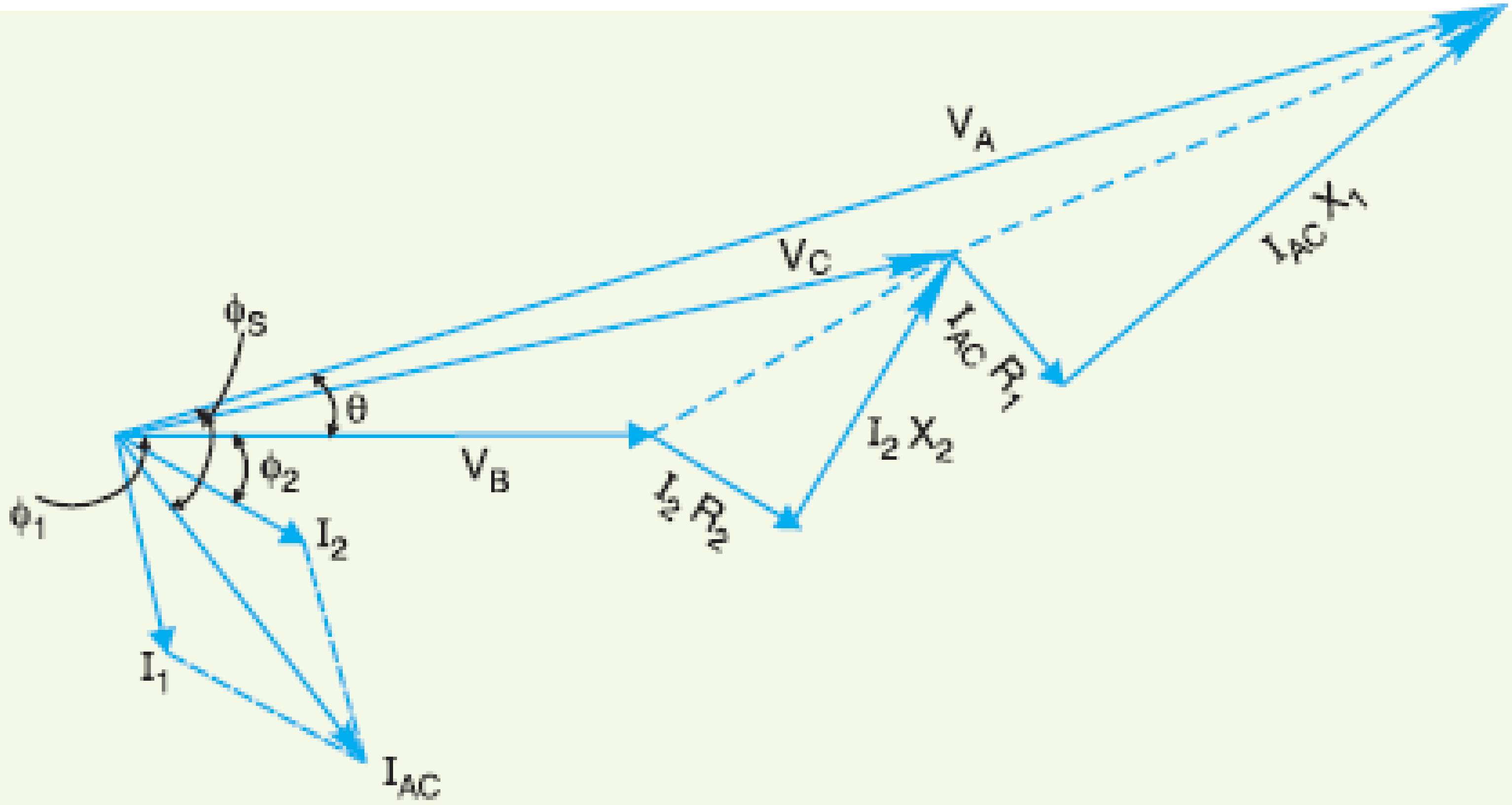
$$= [I_1(\cos\phi_1 - j\sin\phi_1) + I_2(\cos\phi_2 - j\sin\phi_2)]\,[R_1 + jX_1]$$

$$\overrightarrow{V_A} = \overrightarrow{V_B} + \Delta \overrightarrow{V_{CB}} + \Delta \overrightarrow{V_{AC}}$$

$$\overrightarrow{I_A} = \overrightarrow{I_1} + \overrightarrow{I_2}$$

AC Distribution





AC Distribution

(ii) Power factors referred to respective load voltages

φ_1 is the phase angle between V_C and I_1 and φ_2 is the phase angle between V_B and I_2

$$\text{Voltage drop in section } CB = \overrightarrow{I_2}\,\overrightarrow{Z_{CB}} = I_2(\cos\phi_2 - j\sin\phi_2)(R_2 + jX_2)$$

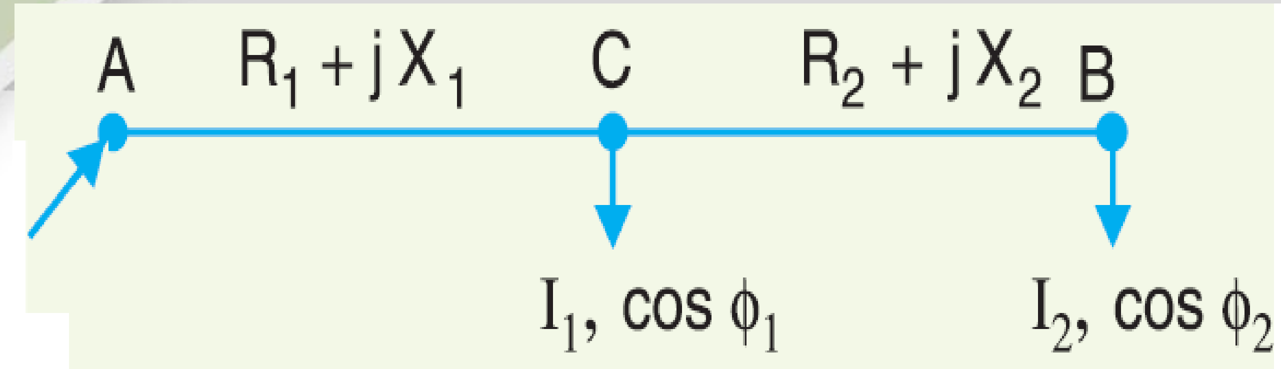
$$\text{Voltage at point } C = \overrightarrow{V_B} + \text{Drop in section } CB = V_C\angle\alpha\ (\text{say})$$

$$I_1 = I_1\angle -\phi_1 \quad w.r.t.\ \text{voltage } V_C \qquad \overline{I_1} = I_1\angle -(\phi_1 - \alpha)\ \ w.r.t.\ \text{voltage } V_B$$

$$\overrightarrow{I_1} = I_1[\cos(\phi_1 - \alpha) - j\sin(\phi_1 - \alpha)]$$

$$\overrightarrow{I_{AC}} = \overrightarrow{I_1} + \overrightarrow{I_2}$$

AC Distribution

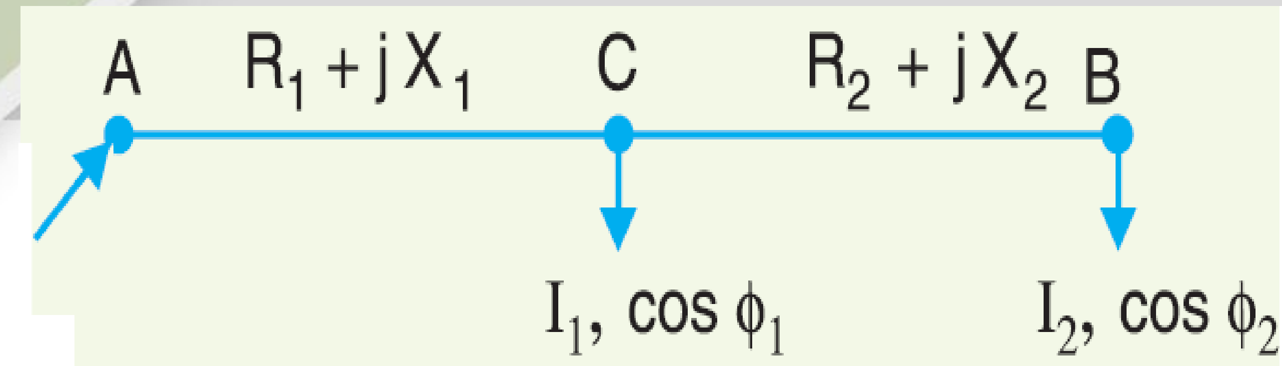


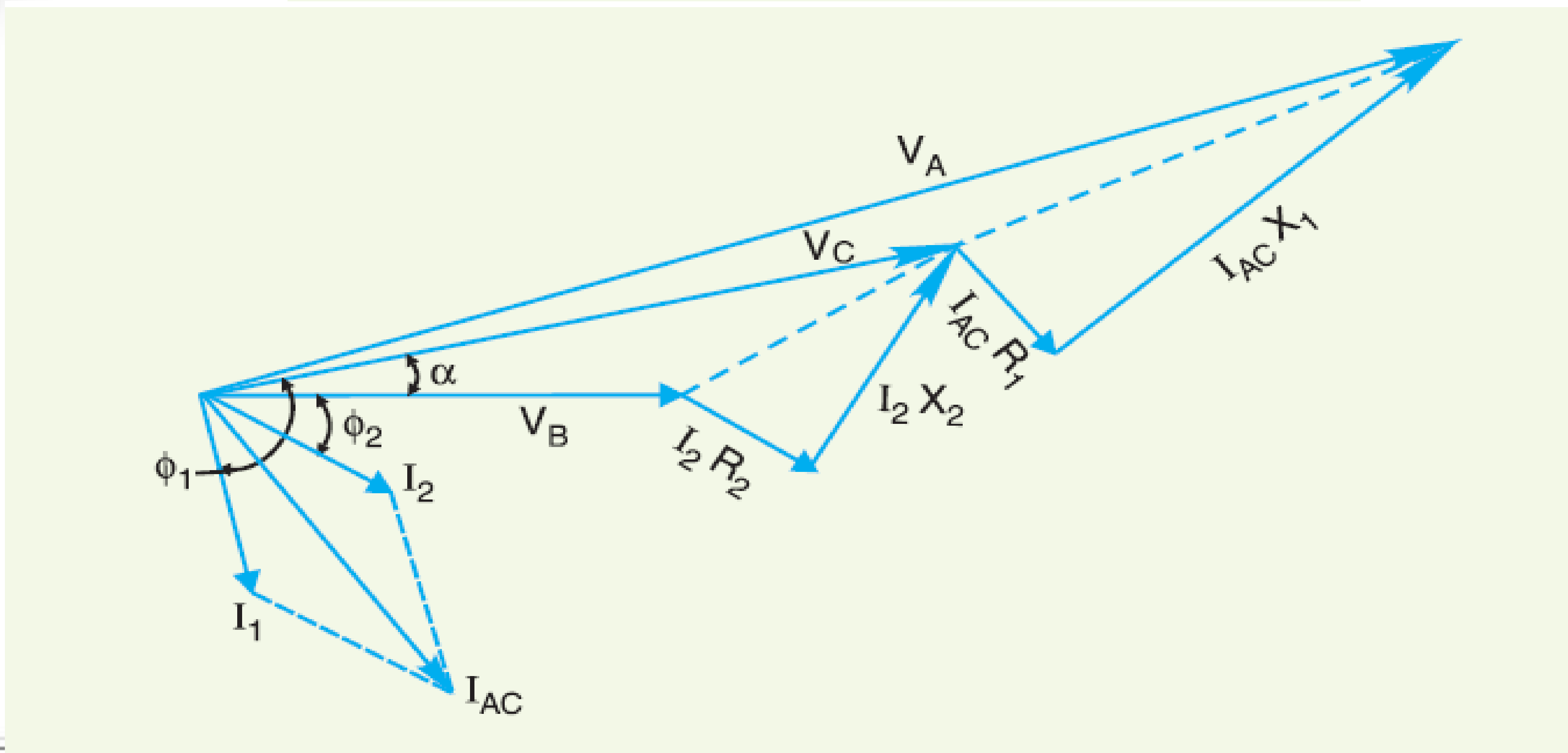
$$\overrightarrow{I_{AC}} = \vec{I_1} + \vec{I_2} = I_1[\cos(\phi_1 - \alpha) - j\sin(\phi_1 - \alpha)] + I_2(\cos\phi_2 - j\sin\phi_2)$$

$$\text{Voltage drop in section } AC = \overrightarrow{I_{AC}}\,\overrightarrow{Z_{AC}}$$

$$\text{Voltage at point } A = V_B + \text{Drop in } CB + \text{Drop in } AC$$

AC Distribution



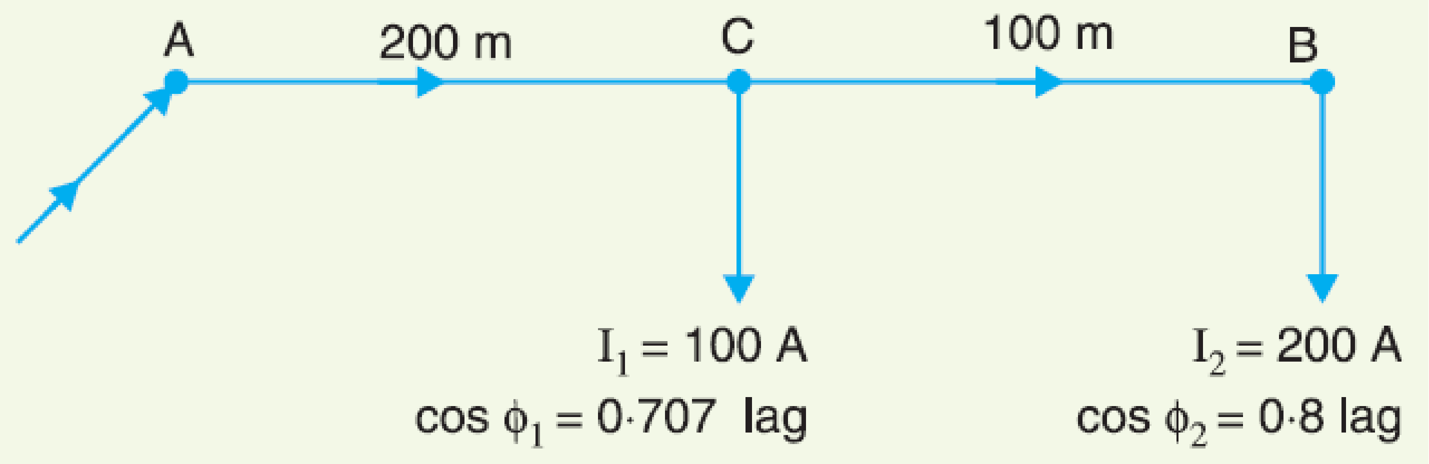


Example: A single phase a.c. distributor AB 300 m long is fed from end A and is loaded as under:

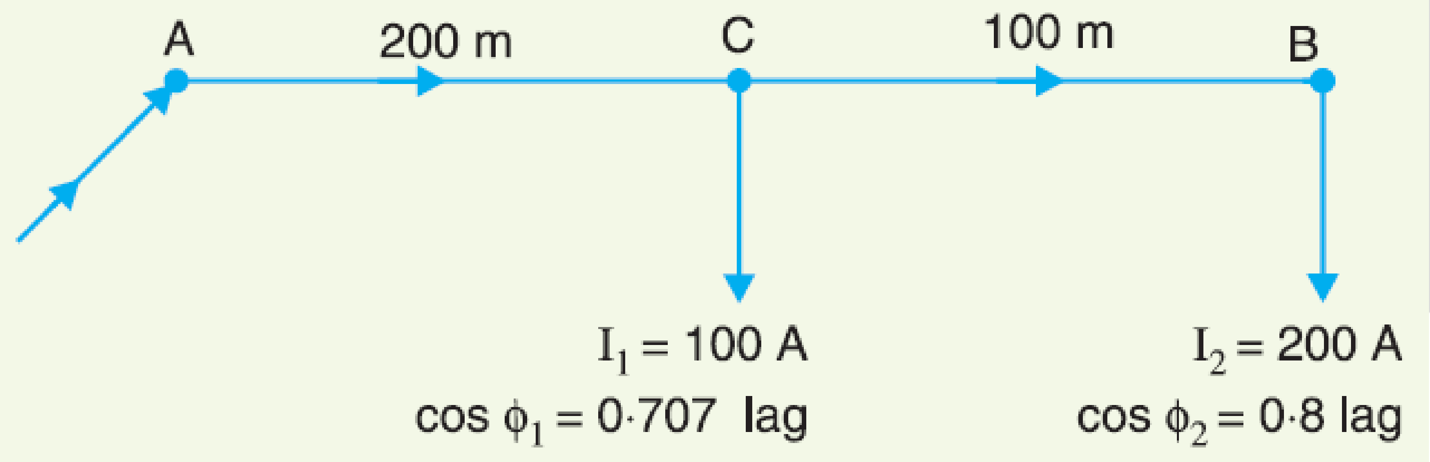
(i) 100 A at 0.707 p.f. lagging 200 m from point A

(ii) 200 A at 0.8 p.f. lagging 300 m from point A

The resistance and reactance of the distributor is 0.2 Ω and 0.1 Ω per km. Calculate the total voltage drop in the distributor. The load power factors refer to the voltage at the far end.



Impedance of distributor/km=(0.2 + j 0.1) Ω



Impedance of section AC, $\overrightarrow{Z_{AC}} = (0{\cdot}2 + j\,0{\cdot}1) \times 200/1000 = (0{\cdot}04 + j\,0{\cdot}02)\ \Omega$

Impedance of section CB, $\overrightarrow{Z_{CB}} = (0{\cdot}2 + j\,0{\cdot}1) \times 100/1000 = (0{\cdot}02 + j\,0{\cdot}01)\ \Omega$

Taking voltage at the far end B as the reference vector, we have,

Load current at point B, $\overrightarrow{I_2} = I_2\,(\cos\phi_2 - j\sin\phi_2) = 200\,(0{\cdot}8 - j\,0{\cdot}6)$

$= (160 - j\,120)$ A

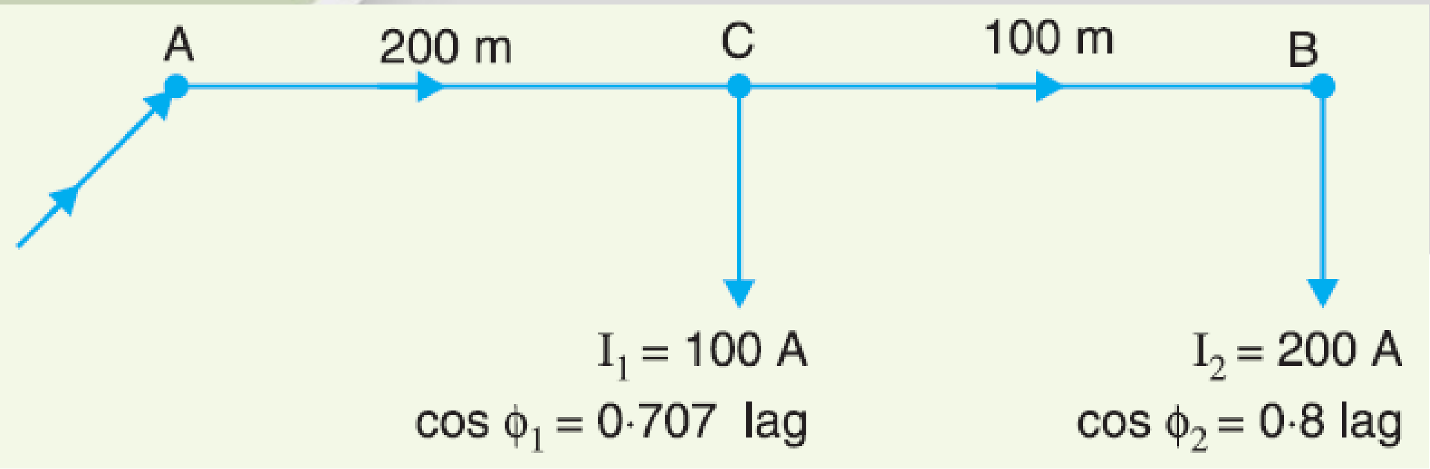
Load current at point C, $\overrightarrow{I_1} = I_1\,(\cos\phi_1 - j\sin\phi_1) = 100\,(0{\cdot}707 - j\,0{\cdot}707)$

$= (70{\cdot}7 - j\,70{\cdot}7)$ A

Current in section CB, $\overrightarrow{I_{CB}} = \overrightarrow{I_2} = (160 - j\,120)$ A

Current in section AC, $\overrightarrow{I_{AC}} = \overrightarrow{I_1} + \overrightarrow{I_2} = (70{\cdot}7 - j\,70{\cdot}7) + (160 - j\,120)$

$= (230{\cdot}7 - j\,190{\cdot}7)$ A



Voltage drop in section CB, $\Delta\overrightarrow{V_{CB}} = \overrightarrow{I_{CB}}\,\overrightarrow{Z_{CB}} = (160 - j\,120)\,(0{\cdot}02 + j\,0{\cdot}01)$

$= (4{\cdot}4 - j\,0{\cdot}8)$ volts

Voltage drop in section AC, $\Delta\overrightarrow{V_{AC}} = \overrightarrow{I_{AC}}\,\overrightarrow{Z_{AC}} = (230{\cdot}7 - j\,190{\cdot}7)\,(0{\cdot}04 + j\,0{\cdot}02)$

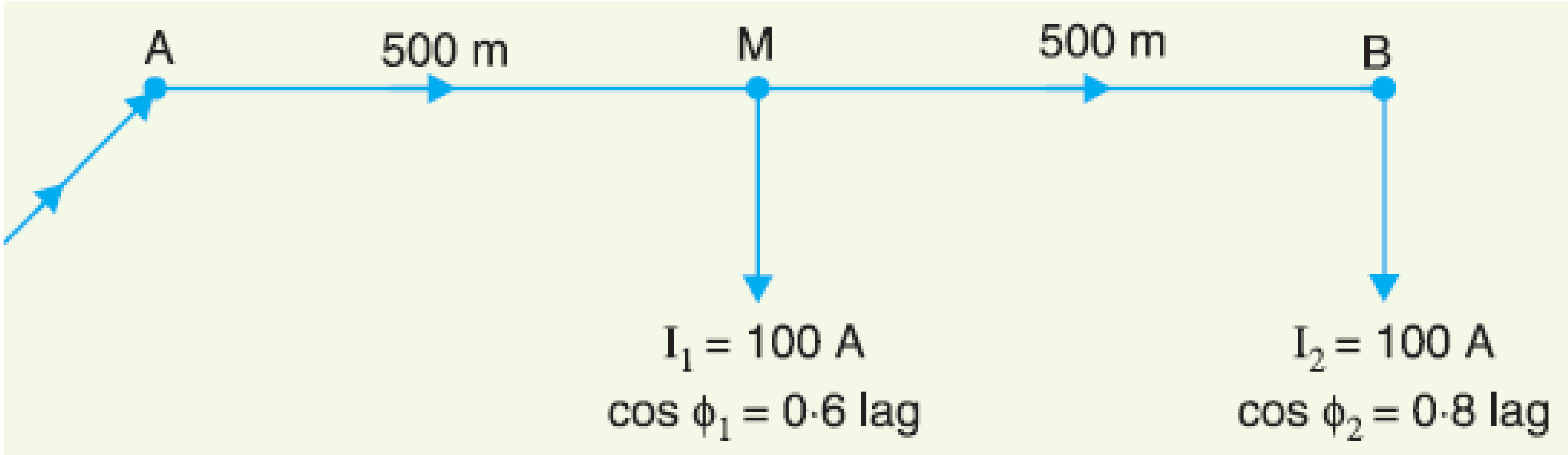
$= (13{\cdot}04 - j\,3{\cdot}01)$ volts

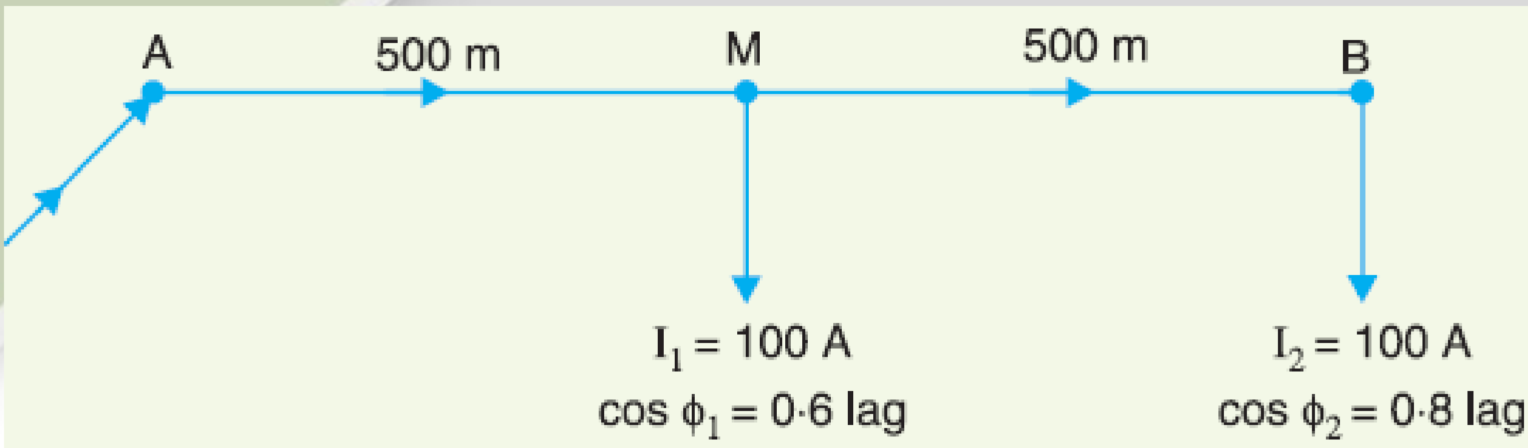
Voltage drop in the distributor $= \overrightarrow{V_{AC}} + \overrightarrow{V_{CB}} = (13{\cdot}04 - j\,3{\cdot}01) + (4{\cdot}4 - j\,0{\cdot}8$

$= (17{\cdot}44 - j\,3{\cdot}81)$ volts

Magnitude of drop $= \sqrt{(17\cdot44)^2 + (3\cdot81)^2} =$ **17·85 V**

Example: A single phase distributor one km long has resistance and reactance per conductor of 0.1 Ω and 0.15 Ω respectively. At the far end, the voltage V_B is 200 V and the current is 100A at a p.f. of 0.8 lagging. At the midpoint M, a current of 100 A is tapped at a p.f. of 0.6 lagging with reference to the voltage at the midpoint. Find: (i) voltage at midpoint (ii) sending end voltage VA (iii) phase angle between V_A and V_B





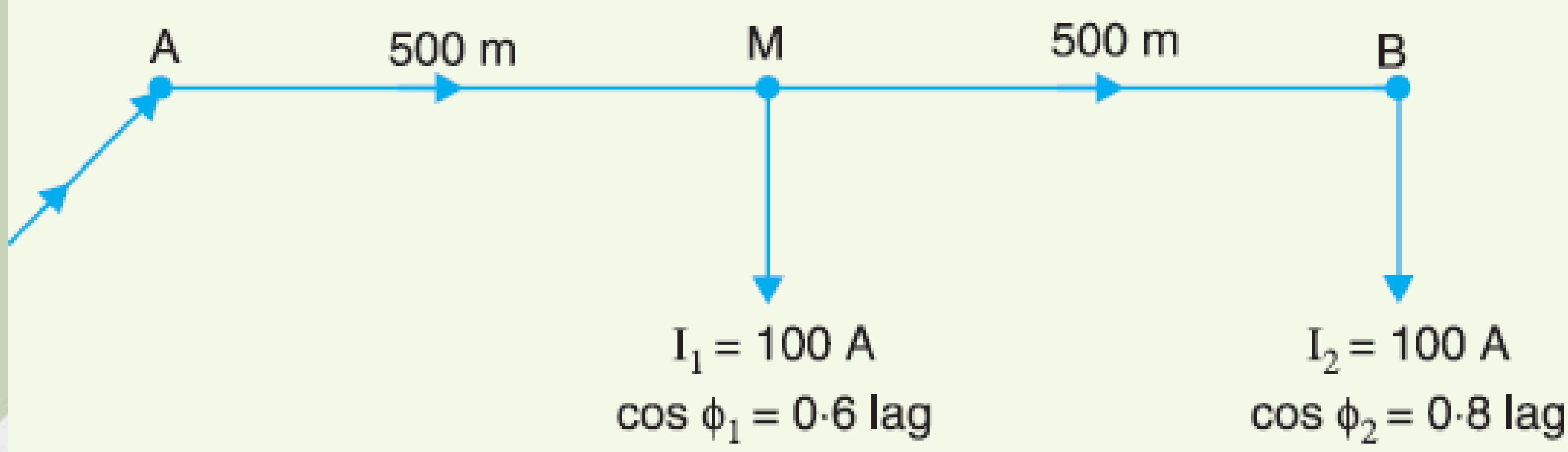
Total impedance of distributor $= 2(0{\cdot}1 + j\,0{\cdot}15) = (0{\cdot}2 + j\,0{\cdot}3)\ \Omega$

Impedance of section *AM*, $\overrightarrow{Z_{AM}} = (0{\cdot}1 + j\,0{\cdot}15)\ \Omega$

Impedance of section *MB*, $\overrightarrow{Z_{MB}} = (0{\cdot}1 + j\,0{\cdot}15)\ \Omega$

Let the voltage V_B at point B be taken as the reference vector.

Then, $\overrightarrow{V_B} = 200 + j\,0$



(*i*) Load current at point *B*, $\vec{I_2} = 100\,(0{\cdot}8 - j\,0{\cdot}6) = 80 - j\,60$

Current in section *MB*, $\overrightarrow{I_{MB}} = \vec{I_2} = 80 - j\,60$

Drop in section *MB*, $\Delta\overrightarrow{V_{MB}} = \overrightarrow{I_{MB}}\,\overrightarrow{Z_{MB}}$

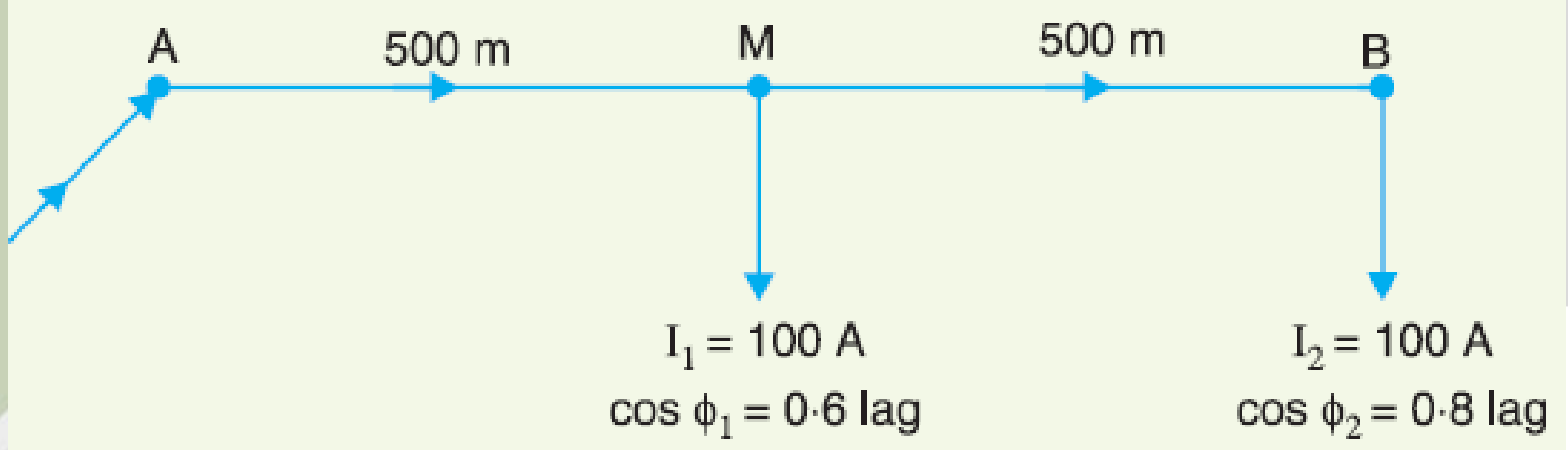
$= (80 - j\,60)\,(0{\cdot}1 + j\,0{\cdot}15) = 17 + j\,6$

$\therefore$ Voltage at point *M*, $\overrightarrow{V_M} = \overrightarrow{V_B} + \overrightarrow{V_{MB}} = (200 + j\,0) + (17 + j\,6)$

$= 217 + j\,6$

Its magnitude is $= \sqrt{(217)^2 + (6)^2} =$ **217·1 V**

Phase angle between V_M and V_B, $\alpha = \tan^{-1} 6/217 = \tan^{-1} 0{\cdot}0276 = 1{\cdot}58°$



(*ii*) The load current I_1 has a lagging p.f. of 0·6 *w.r.t.* V_M. It lags behind V_M by an angle $\phi_1 = \cos^{-1} 0{\cdot}6 = 53{\cdot}13^\circ$

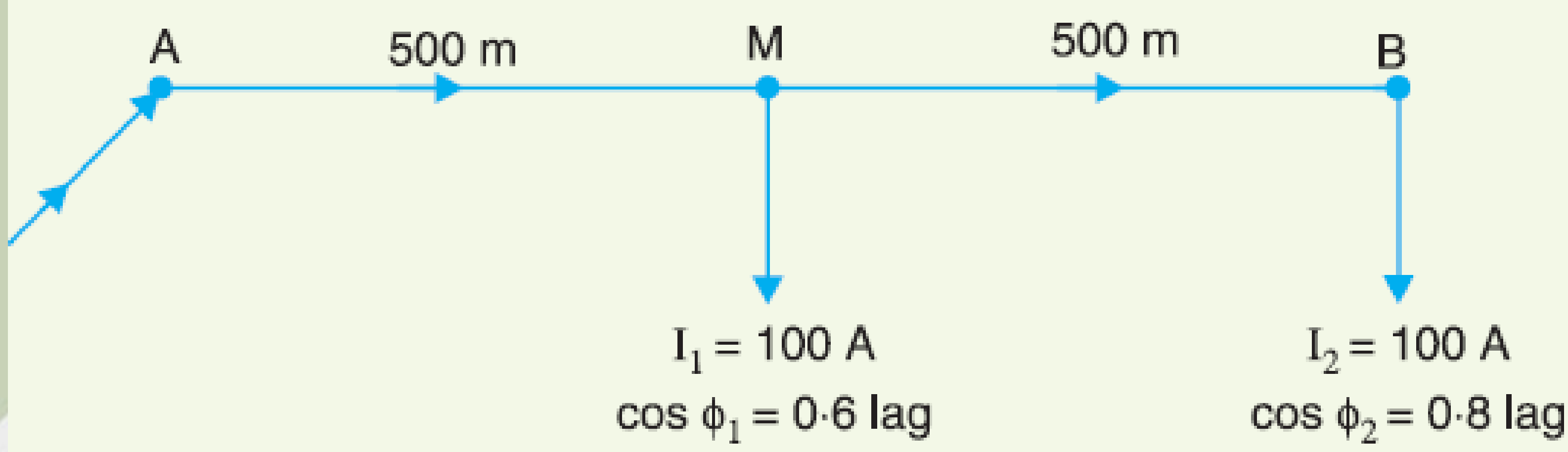
Phase angle between I_1 and V_B, $\phi'_1 \;=\; \phi_1 - \alpha = 53{\cdot}13^\circ - 1{\cdot}58 = 51{\cdot}55^\circ$

$$\text{Load current at } M,\quad \vec{I_1} = I_1(\cos\phi_1' - j\sin\phi_1') = 100(\cos 51{\cdot}55^\circ - j\sin 51{\cdot}55^\circ)$$
$$= 62{\cdot}2 - j\,78{\cdot}3$$

$$\text{Current in section } AM,\quad \overrightarrow{I_{AM}} = \vec{I_1} + \vec{I_2} = (62{\cdot}2 - j\,78{\cdot}3) + (80 - j\,60)$$
$$= 142{\cdot}2 - j\,138{\cdot}3$$

$$\text{Drop in section } AM,\quad \Delta\overrightarrow{V_{AM}} = \overrightarrow{I_{AM}}\,\overrightarrow{Z_{AM}} = (142{\cdot}2 - j\,138{\cdot}3)(0{\cdot}1 + j\,0{\cdot}15)$$
$$= 34{\cdot}96 + j\,7{\cdot}5$$

$$\text{Sending end voltage,}\quad \vec{V_A} = \vec{V_M} + \Delta\overrightarrow{V_{AM}} = (217 + j\,6) + (34{\cdot}96 + j\,7{\cdot}5)$$



Sending end voltage, $\overrightarrow{V_A} = \overrightarrow{V_M} + \Delta\,\overrightarrow{V_{AM}} = (217 + j\,6) + (34{\cdot}96 + j\,7{\cdot}5)$

$$= 251{\cdot}96 + j\,13{\cdot}5$$

Its magnitude is $= \sqrt{(251{\cdot}96)^2 + (13{\cdot}5)^2} = $ **252·32 V**

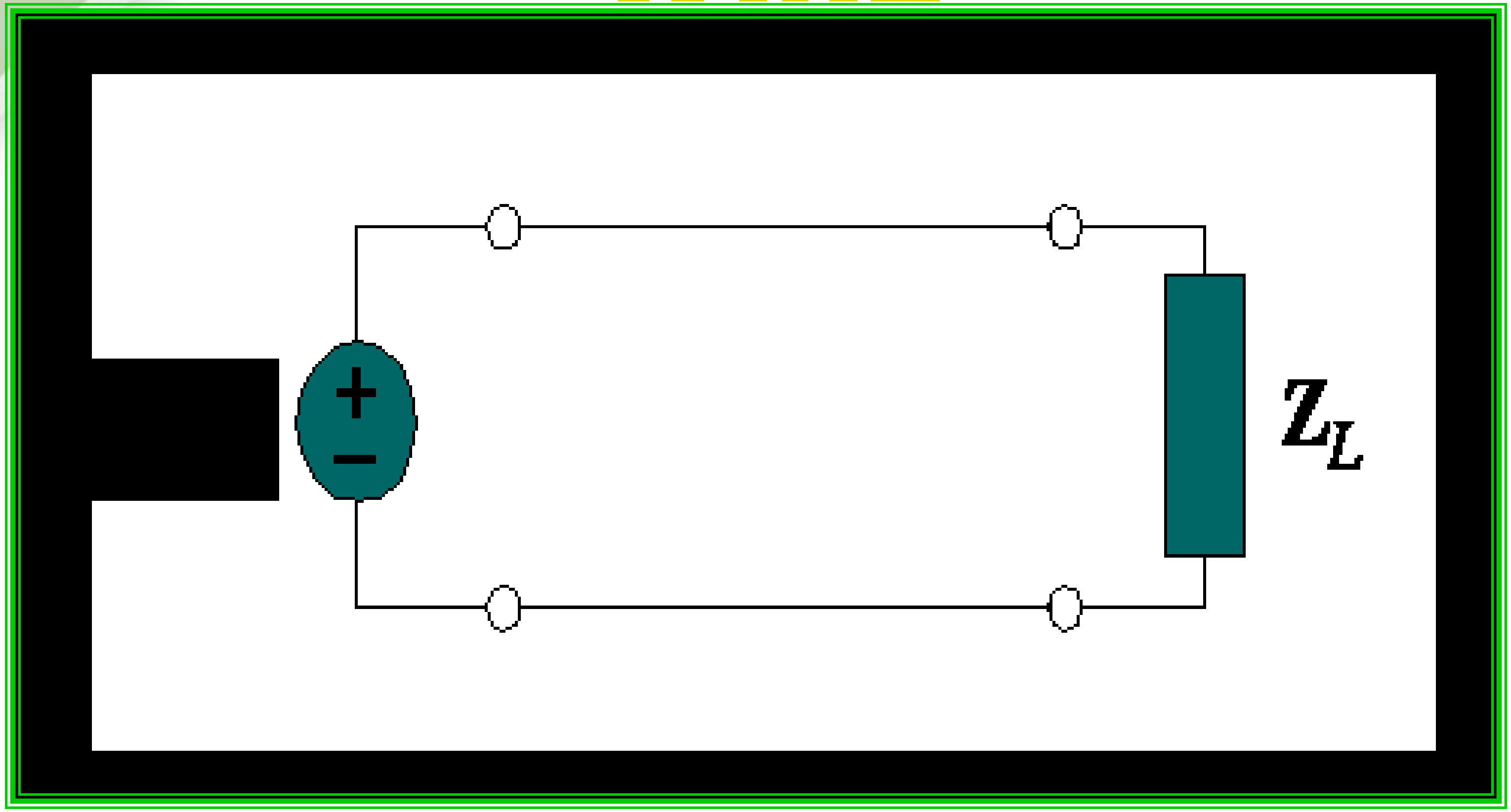
(iii) The phase difference θ between V_A and V_B is given by :

$$\tan\theta = 13{\cdot}5/251{\cdot}96 = 0{\cdot}05358$$

$$\therefore \quad \theta = \tan^{-1} 0{\cdot}05358 = \mathbf{3{\cdot}07^\circ}$$

Hence supply voltage is 252·32 V and leads V_B by 3·07°.

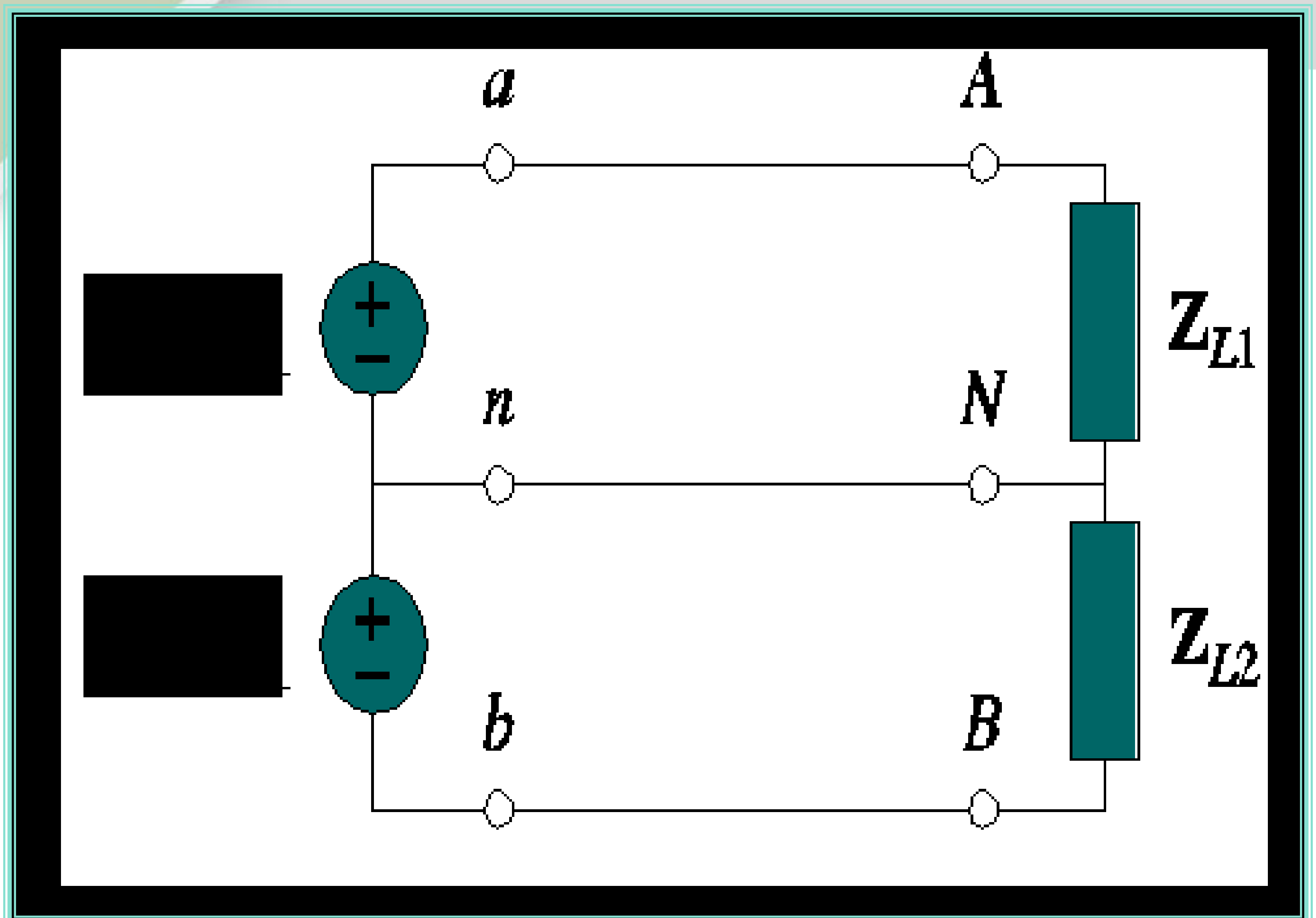
SINGLE PHASE TWO WIRE



SINGLE PHASE SYSTEM

- A generator connected through a pair of wire to a load – Single Phase Two Wire.
- V_p is the magnitude of the source voltage, and ϕ is the phase.

SINLGE PHASE THREE WIRE



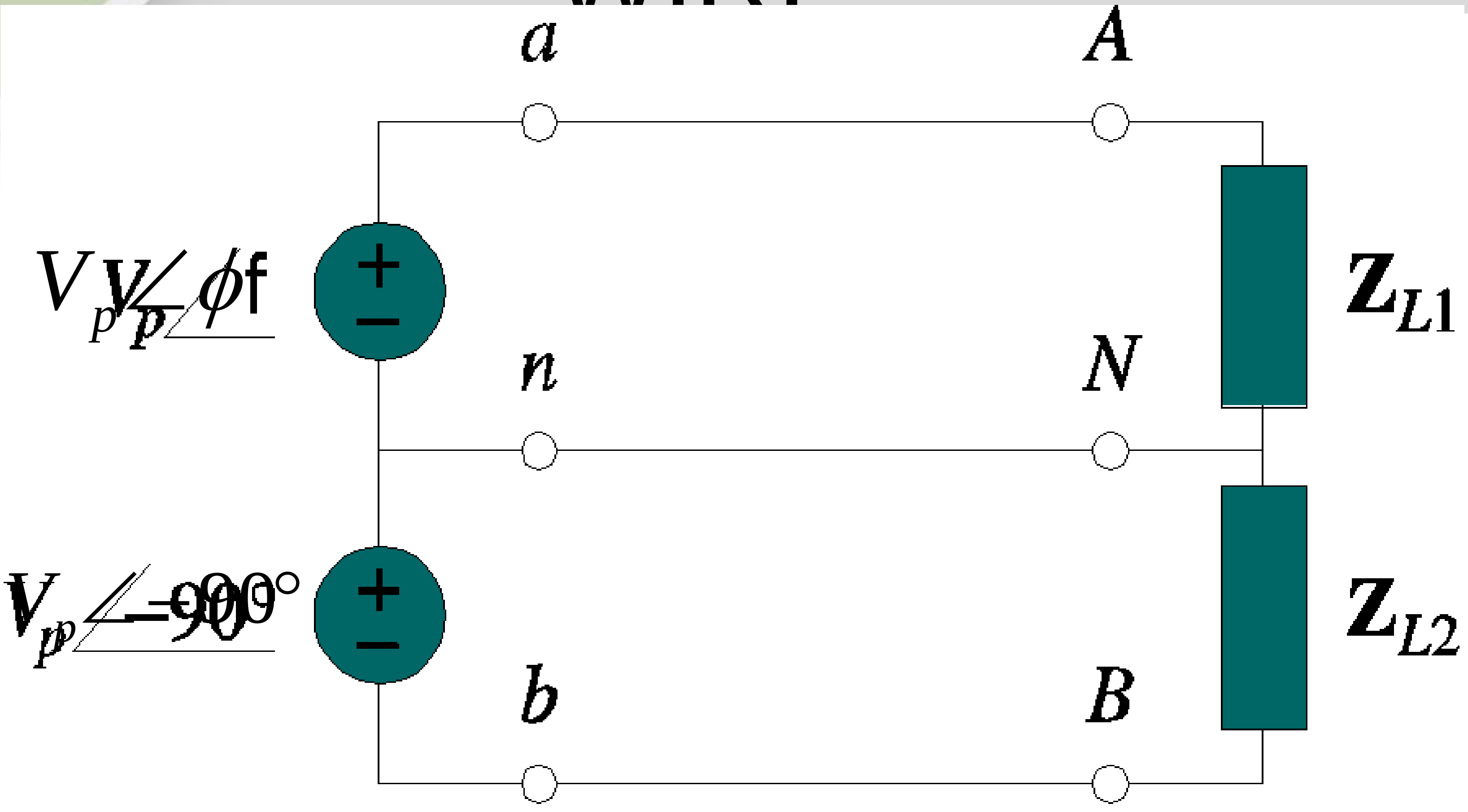
SINGLE PHASE SYSTEM

- Most common in practice: two identical sources connected to two loads by two outer wires and the neutral: Single Phase Three Wire.
- Terminal voltages have same magnitude and the same phase.

POLYPHASE SYSTEM

- Circuit or system in which AC sources operate at the same frequency but different phases are known as polyphase.

TWO PHASE SYSTEM THREE WIRE



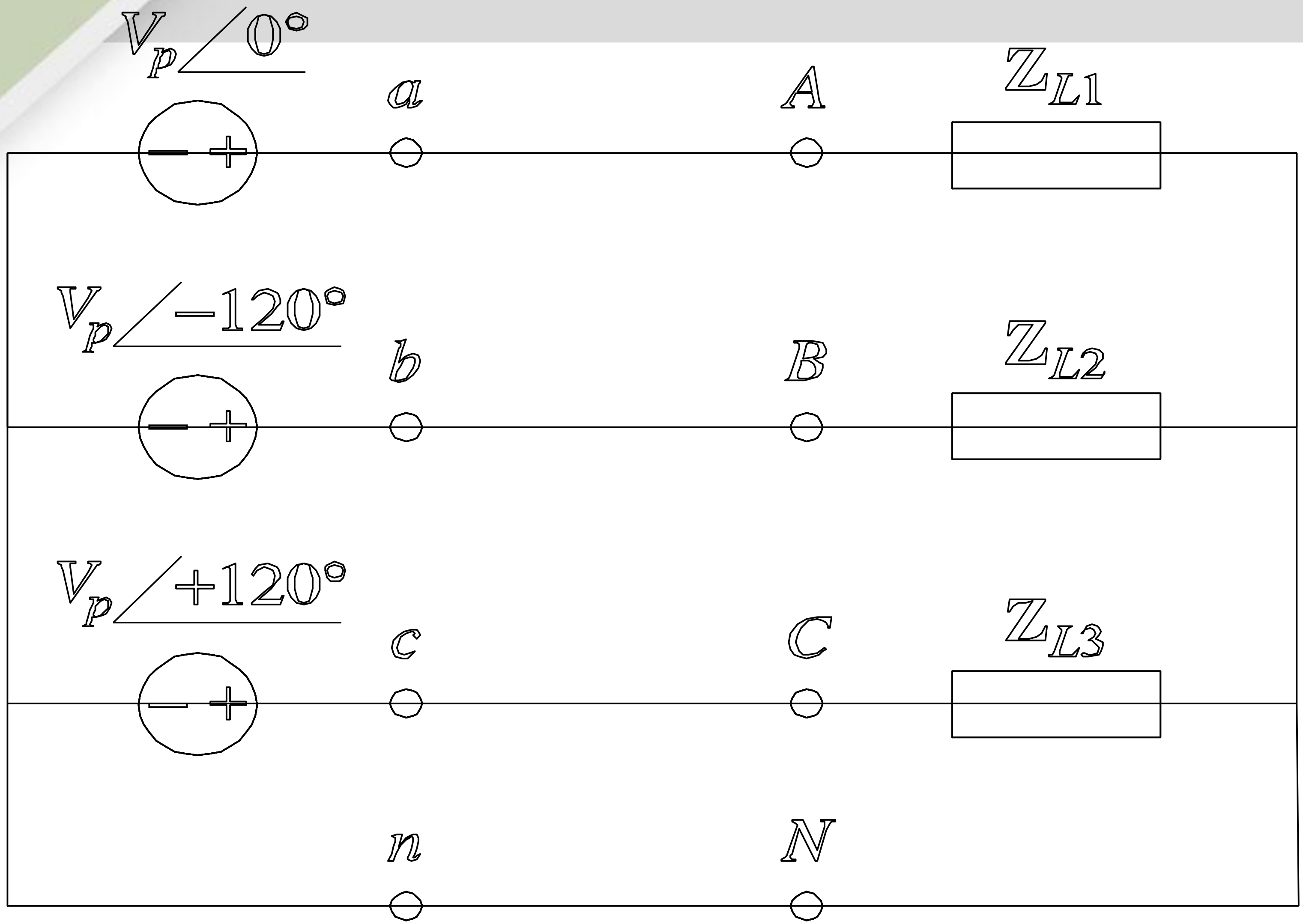
POLYPHASE SYSTEM

- Two Phase System:
  - A generator consists of two coils placed perpendicular to each other
  - The voltage generated by one lags the other by 90°.

POLYPHASE SYSTEM

- Three Phase System:
  - A generator consists of three coils placed 120° apart.
  - The voltage generated are equal in magnitude but, out of phase by 120°.
- Three phase is the most economical polyphase system.

THREE PHASE FOUR WIRE



IMPORTANCE OF THREE PHASE SYSTEM

- All electric power is generated and distributed in three phase.
  - One phase, two phase, or more than three phase input can be taken from three phase system rather than generated independently.
  - Melting purposes need 48 phases supply.

IMPORTANCE OF THREE PHASE SYSTEM

- Uniform power transmission and less vibration of three phase machines.
  - The instantaneous power in a 3ϕ system can be constant (not pulsating).
  - High power motors prefer a steady torque especially one created by a rotating magnetic field.

IMPORTANCE OF THREE PHASE SYSTEM

- Three phase system is more economical than the single phase.
  - The amount of wire required for a three phase system is less than required for an equivalent single phase system.
  - Conductor: Copper, Aluminum, etc

BALANCED 3ϕ VOLTAGES

- Balanced three phase voltages:
  - same magnitude (V_M)
  - 120° phase shift

$$v_{an}(t) = V_M \cos(\omega t)$$

$$v_{bn}(t) = V_M \cos(\omega t - 120°)$$

$$v_{cn}(t) = V_M \cos(\omega t - 240°) = V_M \cos(\omega t + 120°)$$

BALANCED 3ϕ CURRENTS

- Balanced three phase currents:
  - same magnitude (I_M)
  - 120° phase shift

$$i_a(t) = I_M \cos(\omega t - \theta)$$
$$i_b(t) = I_M \cos(\omega t - \theta - 120^\circ)$$
$$i_c(t) = I_M \cos(\omega t - \theta - 240^\circ)$$

PHASE SEQUENCE

$$v_{an}(t) = V_M \cos \omega t$$
$$v_{bn}(t) = V_M \cos(\omega t - 120°)$$
$$v_{cn}(t) = V_M \cos(\omega t + 120°)$$

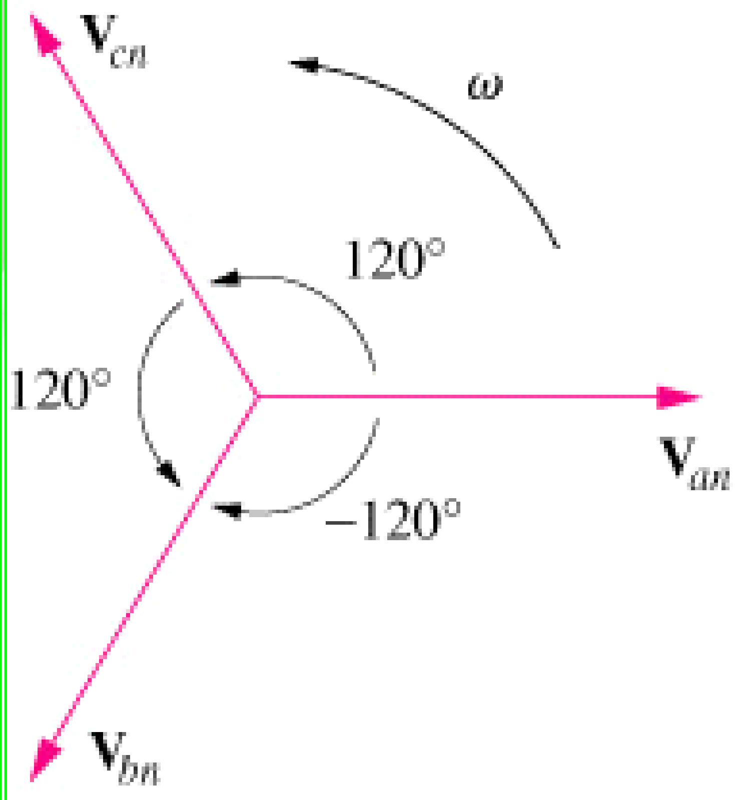
$$V_{an} = V_M \angle 0°$$
$$V_{bn} = V_M \angle -120°$$
$$V_{cn} = V_M \angle +120°$$

POSITIVE SEQUENCE

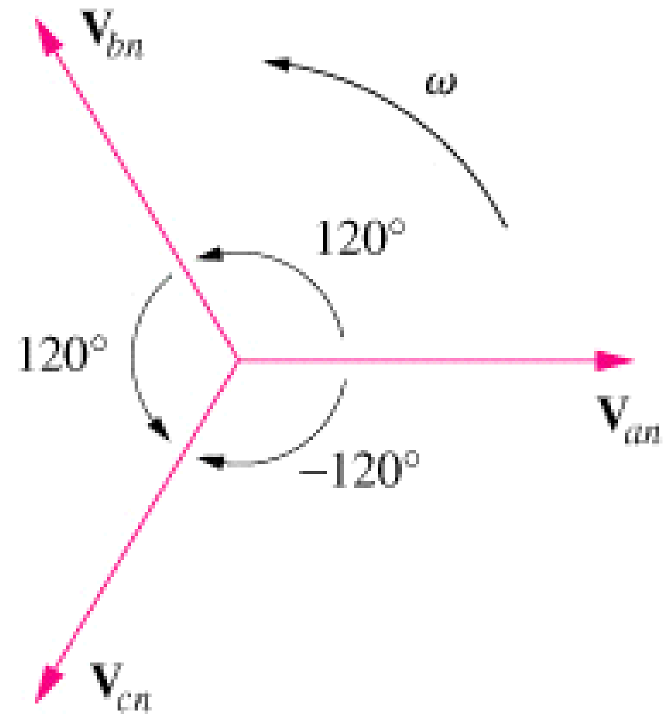
$$V_{an} = V_M \angle 0°$$
$$V_{bn} = V_M \angle +120°$$
$$V_{cn} = V_M \angle -120°$$

NEGATIVE SEQUENCE

PHASE SEQUENCE

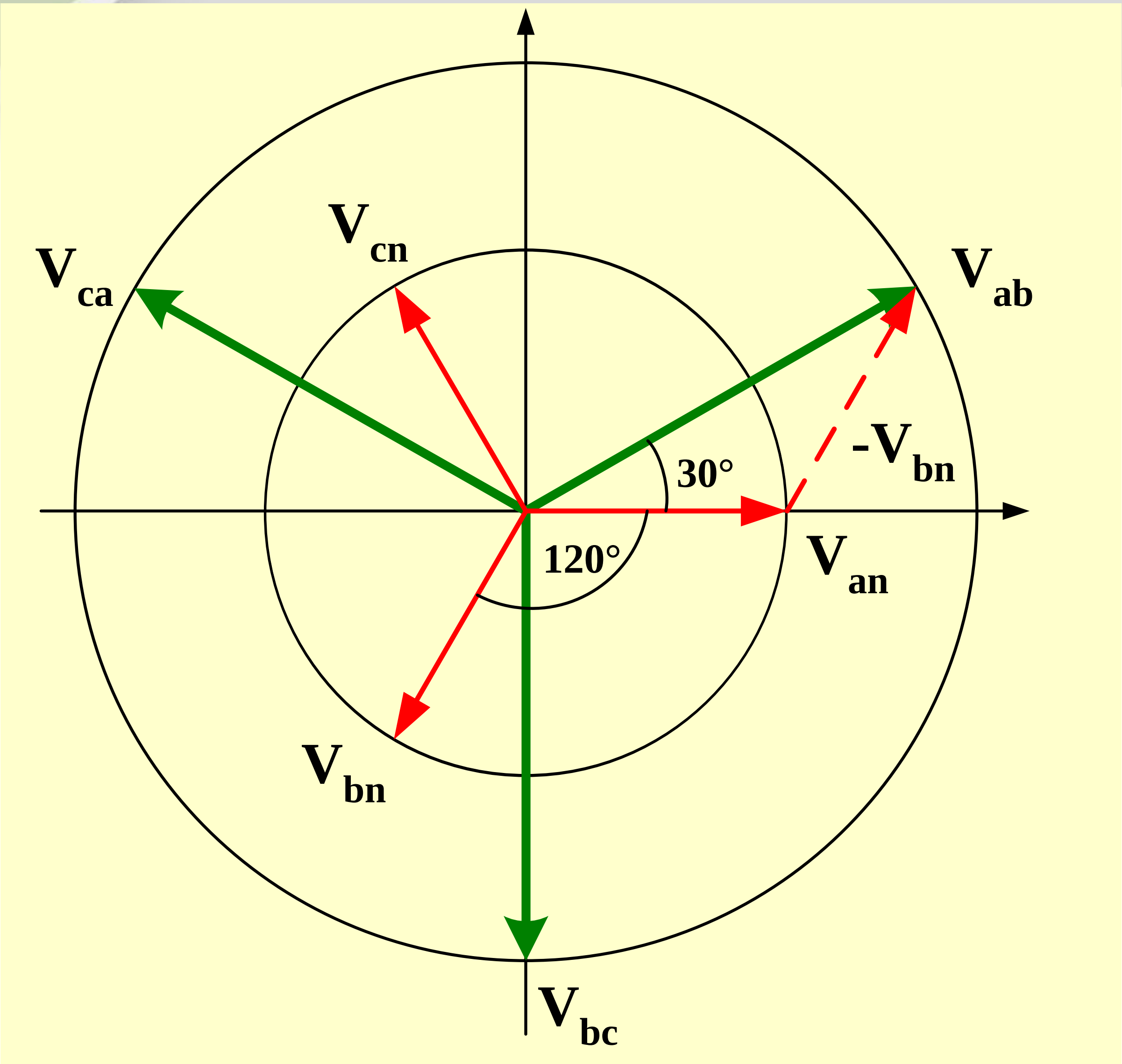


(a)



(b)

PHASE DIAGRAM OF V_L AND V_ϕ



EXAMPLE # 1

- Determine the phase sequence of the set voltages:

$$v_{an} = 200\cos(\omega t + 10^\circ)$$
$$v_{bn} = 200\cos(\omega t - 230^\circ)$$
$$v_{cn} = 200\cos(\omega t - 110^\circ)$$

BALANCED VOLTAGE AND LOAD

- Balanced Phase Voltage: all phase voltages are equal in magnitude and are out of phase with each other by 120°.
- Balanced Load: the phase impedances are equal in magnitude and in phase.

THREE PHASE QUANTITIES

QUANTITY	SYMBOL
Phase current	I_ϕ
Line current	I_L
Phase voltage	V_ϕ
Line voltage	V_L

PHASE VOLTAGES and LINE VOLTAGES

- Phase voltage is measured between the neutral and any line: line to neutral voltage
- Line voltage is measured between any two of the three lines: line to line voltage.

PHASE CURRENTS and LINE CURRENTS

- Line current (I_L) is the current in each line of the source or load.
- Phase current (I_ϕ) is the current in each phase of the source or load.

SOURCE-LOAD CONNECTION

SOURCE	LOAD	CONNECTION
Wye	Wye	Y-Y
Wye	Delta	Y-Δ
Delta	Delta	Δ- Δ
Delta	Wye	Δ-Y

Three-phase AC Distribution

1. Four-wire star-connected unbalanced load
2. Unbalanced delta-connected load
3. Unbalanced 3-wire, star-connected load

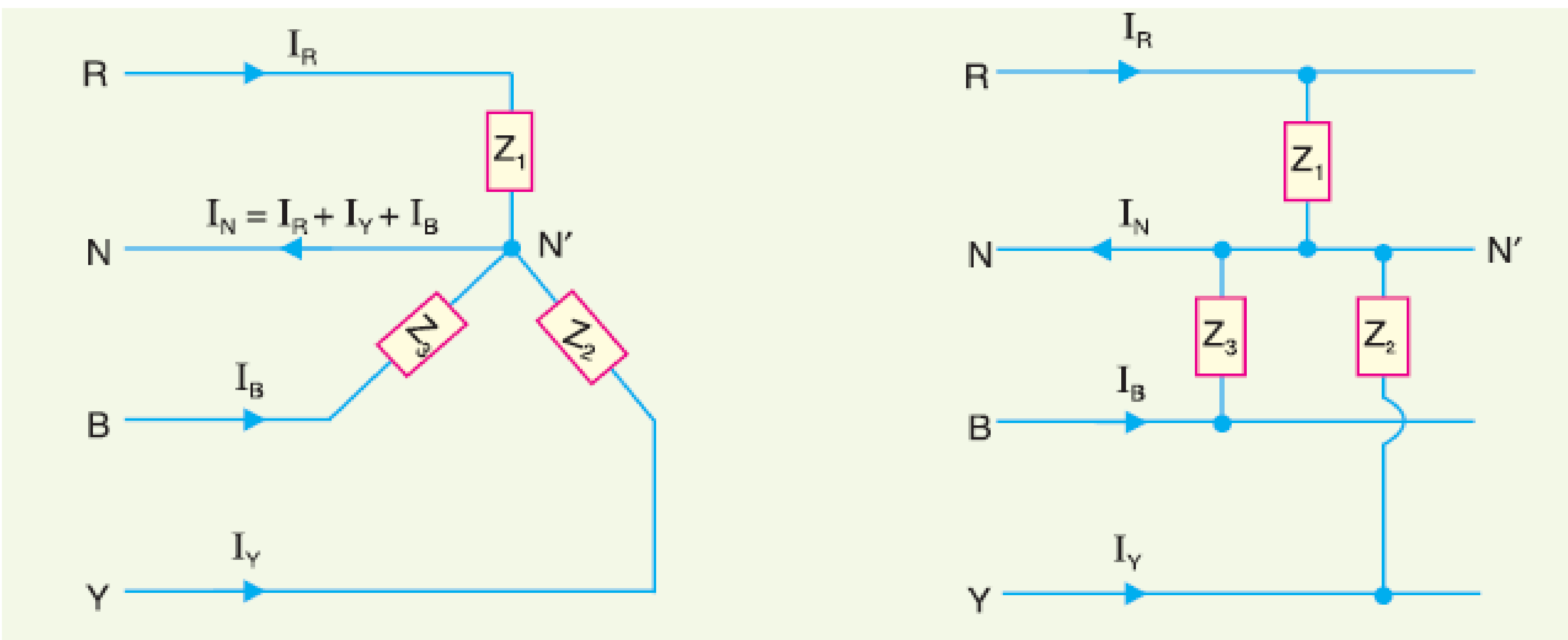
The 3-phase, 4-wire system is widely used for distribution of electric power in commercial and industrial buildings.

The single phase load is connected between any line and neutral wire while a 3-phase load is connected across the three lines.

Four-wire star-connected unbalanced load

Since the load is unbalanced, the line currents will be different in magnitude and displaced from one another by unequal angles. The current in the neutral wire will be the phasor sum of the three line currents i.e.

$$\bar{I}_N = \bar{I}_R + \bar{I}_B + \bar{I}_Y$$



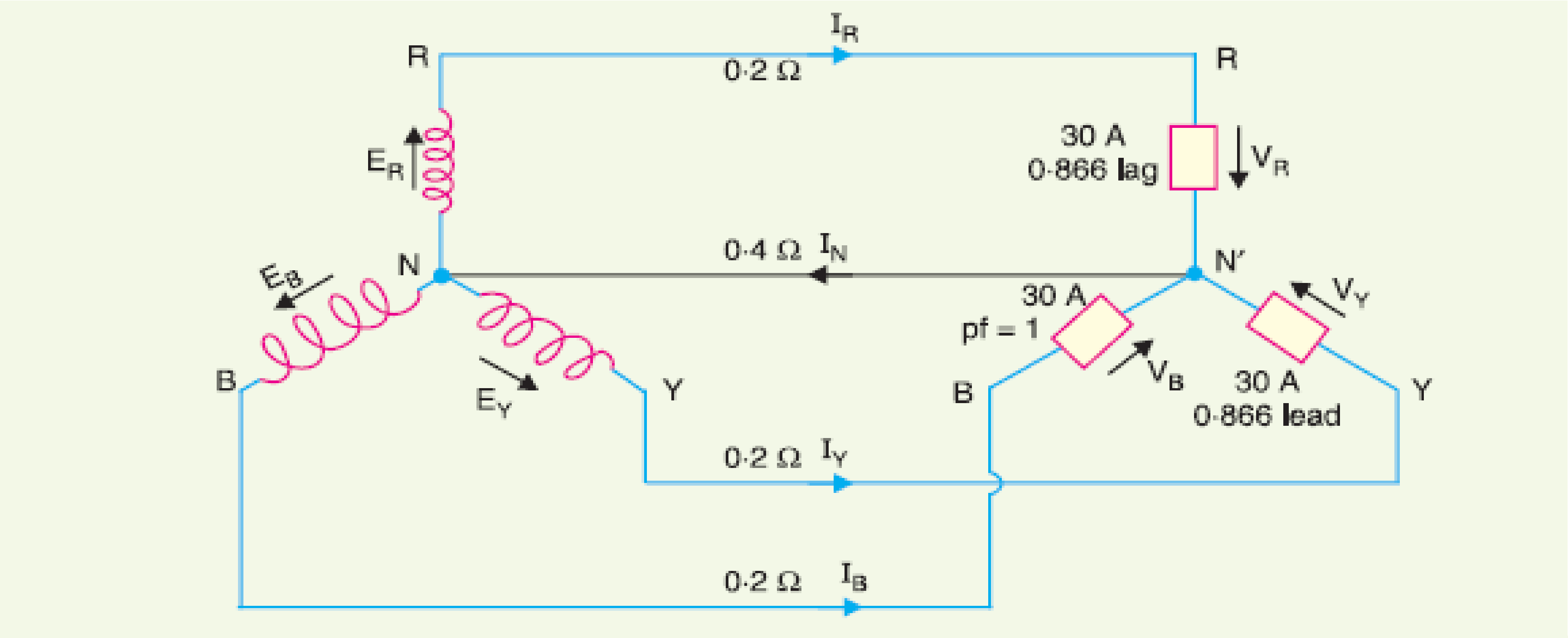
Three phase load single phase loads

Four-wire star-connected unbalanced load

A 3-phase, 4-wire distributor supplies a balanced voltage of 400/230 V to a load consisting of 30 A at p.f. 0·866 lagging for R-phase, 30 A at p.f. 0·866 leading for Y phase and 30 A at unity p.f. for B phase. The resistance of each line conductor is 0·2 Ω. The area of X-section of neutral is half of any line conductor. Calculate the supply end voltage for R phase. The phase sequence is RYB.

Solution. The circuit diagram is shown in Fig. 14.19. Since neutral is half the cross-section, its resistance is 0·4 Ω. Considering the load end and taking V_R as the reference vector, the phase voltages can be written as :

$$\vec{V_R} = 230 \angle 0^\circ \text{ volts} \;;\; \vec{V_Y} = 230 \angle -120^\circ \text{ volts} \;;\; \vec{V_B} = 230 \angle 120^\circ \text{ volts}$$



Four-wire star-connected unbalanced load

Solution

The vector diagram of the circuit is shown in Fig. 14.20. The line current I_R lags behind V_R by an angle $\cos^{-1} 0{\cdot}866 = 30^\circ$. The current I_Y leads V_Y by 30° and the current I_B is in phase with V_B. Referring to the vector diagram of Fig.14.20, the line currents can be expressed as :

$$\vec{I_R} = 30 \angle -30^\circ \text{ amperes}$$

$$\vec{I_Y} = 30 \angle -90^\circ \text{ amperes}$$

$$\vec{I_B} = 30 \angle 120^\circ \text{ amperes}$$

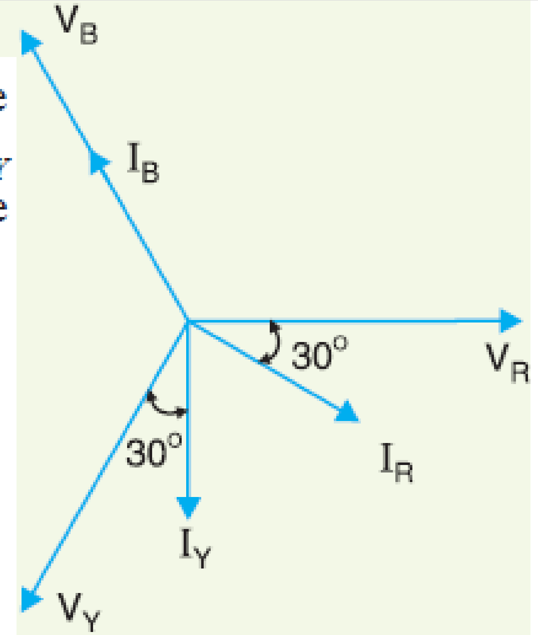


Fig. 14.20

Current in neutral wire,

$$\begin{aligned} \vec{I_N} &= \vec{I_R} + \vec{I_Y} + \vec{I_B} \\ &= 30 \angle -30^\circ + 30 \angle -90^\circ + 30 \angle 120^\circ \\ &= 30\,(0{\cdot}866 - j\,0{\cdot}5) - 30\,(j) + 30\,(-0{\cdot}5 + j\,0{\cdot}866) \\ &= 10{\cdot}98 - j\,19{\cdot}02 \end{aligned}$$

Four-wire star-connected unbalanced load

Let the supply voltage of phase R to neutral be $\overrightarrow{E_R}$. Then,

$$\begin{aligned}
\overrightarrow{E_R} &= \overrightarrow{V_R} + \text{Drop in } R \text{ phase} + \text{Drop in neutral} \\
&= (230 + j\,0) + 0{\cdot}2 \times 30 \angle -30^\circ + (10{\cdot}98 - j\,19{\cdot}02) \times 0{\cdot}4 \\
&= 230 + 6\,(0{\cdot}866 - j\,0{\cdot}5) + 0{\cdot}4\,(10{\cdot}98 - j\,19{\cdot}02) \\
&= 239{\cdot}588 - j\,10{\cdot}608 \\
&= \mathbf{239{\cdot}8 \angle -2{\cdot}54^\circ \text{ volts}}
\end{aligned}$$

Four-wire star-connected unbalanced load

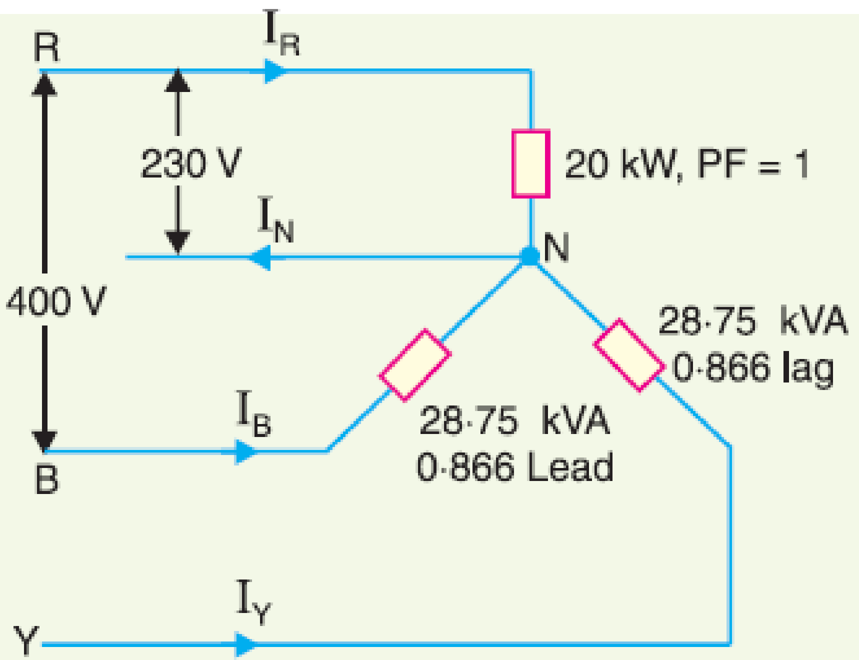
Example 14.9. *The three line leads of a 400/230 V, 3-phase, 4-wire supply are designated as R, Y and B respectively. The fourth wire or neutral wire is designated as N. The phase sequence is RYB. Compute the currents in the four wires when the following loads are connected to this supply :*

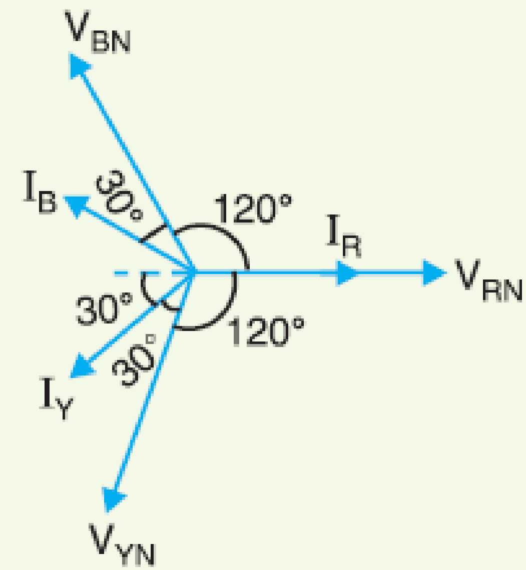
From R to N : 20 kW, unity power factor

From Y to N : 28·75 kVA, 0·866 lag

From B to N : 28·75 kVA, 0·866 lead

If the load from B to N is removed, what will be the value of currents in the four wires ?





Four-wire star-connected unbalanced load

Solution. Fig. 14.17 shows the circuit diagram whereas Fig.14.18 shows its phasor diagram. The current I_R is in phase with V_{RN}, current I_Y lags behind its phase voltage V_{YN} by $\cos^{-1} 0{\cdot}866 = 30°$ and the current I_B leads its phase voltage V_{BN} by $\cos^{-1} 0{\cdot}866 = 30°$.

$$I_R = 20 \times 10^3/230 = \mathbf{89{\cdot}96\ A}$$

$$I_Y = 28{\cdot}75 \times 10^3/230 = \mathbf{125\ A}$$

$$I_B = 28{\cdot}75 \times 10^3/230 = \mathbf{125\ A}$$

The current in the neutral wire will be equal to the phasor sum of the three line currents I_R, I_Y and I_B. Referring to the phasor diagram in Fig.14.18 and resolving these currents along x-axis and y-axis, we have,

Resultant X-component $= 86{\cdot}96 - 125 \cos 30° - 125 \cos 30°$

$= 86{\cdot}96 - 108{\cdot}25 - 108{\cdot}25 = -\ 129{\cdot}54$ A

Resultant Y-component $= 0 + 125 \sin 30° - 125 \sin 30° = 0$

∴ Neutral current, $I_N = \sqrt{(-129 \cdot 54)^2 + (0)^2} = \mathbf{129{\cdot}54A}$

Four-wire star-connected unbalanced load

When load from B to N removed. When the load from B to N is removed, the various line currents are :

I_R = **86·96A** in phase with V_{RN} ; I_Y = **125A** lagging V_{YN} by 30° ; I_B = **0 A**

The current in the neutral wire is equal to the phasor sum of these three line currents. Resolving the currents along x-axis and y-axis, we have,

Resultant X-component $= 86{\cdot}96 - 125 \cos 30^\circ = 86{\cdot}96 - 108{\cdot}25 = -21{\cdot}29$ A

Resultant Y-component $= 0 - 125 \sin 30^\circ = 0 - 125 \times 0{\cdot}5 = -62{\cdot}5$ A

$\therefore$ Neutral current, $I_N = \sqrt{(-21{\cdot}29)^2 + (-62{\cdot}5)^2} = \mathbf{66{\cdot}03\ A}$

Comparison of Conductor Material in Overhead System

(i) same power (*P watts*) transmitted by each system.

(*ii*) the distance (*l metres*) over which power is transmitted remains the same.

(*iii*) the line losses (*W watts*) are the same in each case.

(*iv*) the maximum voltage between any conductor and earth (*Vm*) is the same in each case.

Comparison of 3-wire and 2-wire D.C. distribution

- It will be shown that there is a great saving of conductor material if we use 3-wire system instead of 2-wire system for d.c. distribution.
- For comparison, it will be assumed that:

i. The amount of power *P* transmitted is the same
ii. The voltage *V* at the consumer's terminals is the same
iii. The distance of transmission is the same
iv. The efficiency of transmission (and hence losses) is the same
v. The 3-wire system is balanced i.e. no current in the neutral wire
vi. The area of X-section of neutral wire is half the cross-section of outers in 3-wire system

Comparison of 3-wire and 2-wire D.C. distribution

Let R_2 = resistance of each conductor in 2-wire system

R_3 = resistance of each outer in 3-wire system

Current through outers in case of 3-wire system is

$$I_3 = \frac{P}{2V}$$

Total losses in two outers $\quad P_{loss} = 2I_3^2R_3 = 2\left(\frac{P}{2V}\right)^2 R_3$

Current through conductor in case of 2-wire system is

$$I_2 = \frac{P}{V}$$

Total losses $\quad P_{loss} = 2I_2^2R_2 = 2\left(\frac{P}{V}\right)^2 R_2$

Since efficiency of transmission is the same, it means losses are the same i.e.

Comparison of 3-wire and 2-wire D.C. distribution

Since efficiency of transmission is the same, it means losses are the same i.e.

$$2\left(\frac{P}{2V}\right)^2 R_3 = 2\left(\frac{P}{V}\right)^2 R_2$$

$$R_3 = 4R_2$$

Therefore, the area of X-section of outers in 3-wire case will be one-fourth of each conductor in 2-wire system.

Let a = area of X-section of each conductor in 2-wire system

Then a/4 = area of X-section of each outer in 3-wire system

And a/8 = area of X-section of each neutral in 3-wire system

If L is the length of the line, then,

Volume of Cu for 3-wire system $= \mathrm{L}\left(\frac{a}{4} + \frac{a}{4} + \frac{a}{8}\right) = \frac{5}{8} a\, L$

Comparison of 3-wire and 2-wire D.C. distribution

Volume of Cu for 2-wire system $= \mathrm{L}(\boldsymbol{a}+\boldsymbol{a}) = \mathbf{2}\boldsymbol{a}\,\boldsymbol{L}$

$$\frac{\textbf{Volume of Cu for 3-wire system}}{\textbf{Volume of Cu for 2-wire system}} = \frac{5}{8}\boldsymbol{a}\,\boldsymbol{L} \times \frac{1}{2\boldsymbol{a}\,\boldsymbol{L}} = \frac{5}{16}$$

Hence a 3-wire system requires only 5/16th (or 31.25%) as much copper as a 2-wire system.

If the neutral has the same X-section as the outer, then,

Volume of Cu for 3-wire system $= \mathrm{L}\left(\frac{\boldsymbol{a}}{4}+\frac{\boldsymbol{a}}{4}+\frac{\boldsymbol{a}}{4}\right) = \frac{3}{4}\boldsymbol{a}\,\boldsymbol{L}$

Volume of Cu for 2-wire system $= \mathrm{L}(\boldsymbol{a}+\boldsymbol{a}) = \mathbf{2}\boldsymbol{a}\,\boldsymbol{L}$

$$\frac{\textbf{Volume of Cu for 3-wire system}}{\textbf{Volume of Cu for 2-wire system}} = \frac{3}{4}\boldsymbol{a}\,\boldsymbol{L} \times \frac{1}{2\boldsymbol{a}\,\boldsymbol{L}} = \frac{3}{8}$$

Hence a 3-wire system requires only 3/8th (or 37.5%) as much copper as a 2-wire system.